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CONTENTS.

CHAPTER I.

GENERAL.

CHAPTER II.

RECONNAISSANCE AND SURVEY.

CHAPTER III.

THE PRINCIPLES OF ROAD CONSTRUCTION

CHAPTER IV.

PERMANENT MACADAM ROADS.

CHAPTER V.

ROADS, &c., DURING NORMAL OPERATIONS IN A SMALL WAR.

CHAPTER VI.

ROADS, &c., FOR THE OPERATIONS OF A LARGE FORCE DURING PERIOD OF STATIONARY WARFARE.

CHAPTER VII.

MOUNTAIN ROADS.

CHAPTER VIII.

MASONRY STRUCTURES IN ROAD-WORK.

CHAPTER IX.

PAVED ROADWAYS.

LIST OF PLATES.

(At end of volume.)

LIST OF PLATES—*continued*.

LIST OF TABLES.

LIST OF APPENDICES.

ROADS.

CHAPTER I.

GENERAL.

1. *Introductory.*

1. "Strategy is a constant science, its rules to-day are similar to those in the time of Cæsar." Just as the Romans found the necessity for military road construction in all their theatres of war, so must the movements of a modern army be governed by the roads available to carry the columns of troops and transport in all strategical concentrations. The ruling factor in the equipment of an expedition as regards the nature of its transport will be the condition of the existing roads in the country, and the importance of accurate information regarding these must be borne in mind in compiling intelligence reports.

Experience has shown that good roads contribute very largely to the success of all operations, and there have been many instances in which the breakdown of all means of communication has rendered initial success of no avail, and allowed the enemy time to recover himself and organize his resistance.

2. Military road making must be studied as much from the point of view of expediency and strategy as from the financial standpoint. In the face of the enemy, military requirements in the way of free and rapid movement of artillery, troops, and stores become paramount, and such work as is necessary to enable the commander to carry out his strategical plan must be executed with all possible speed. The chief consideration will be economy of labour and material, in order that other important engineer works may not be affected adversely.

2. *Traffic considerations.*

The main essential in every road is for the subgrade and foundation to be strong enough to bear the traffic brought on it. Without this no road, however good the surface, will last for more than a short time.

The best available material should be used, and the construction should follow the lines of modern practice as closely as consideration of time and labour will permit.

The types of vehicles which may require to use a road will depend on the nature of the campaign, and the proximity and character of the enemy. Nor should it be forgotten that, as the military situation changes, a road constructed for one class of transport may be required to carry heavier loads. The military engineer must, therefore, be in possession of detailed particulars of the dimensions and loads of the principal vehicles and guns with which the army is equipped: these are given in Military Engineering, Vol. III, Chap. III.

3. *Topographical considerations.*

The conformation of the ground and the prevalent local conditions necessarily influence the location and construction of roads.

Each type of country possesses its particular characteristics. With mountain roads the chief characteristics are difficulties of gradients and sharp curves; those of roads in flat country are difficulties of foundation and drainage. In marshy sites very careful drainage is necessary, and in a desert country special measures are necessary to spread the load over as large an area as possible.

The principles of construction in the various types of country are dealt with in subsequent chapters.

4. *Military considerations.*

As stated in Sec. **1**, the equipment of an expedition is in the first instance usually dependent on the communications already existing in the theatre of operations. All types of road, however, will usually be required to a greater or less extent in any class of campaign.

The tendency in undeveloped countries will always be to supplant the more tedious methods of transport by the use of heavier vehicles up to the farthest point possible, and these will require more solidly constructed roads.

5. *Roads as they affect an engineer officer.*

The execution of all military works involving road construction, both on active service and in peace-time, will generally devolve on the Royal Engineers.

On active service, the engineer officer will have to provide, in the best location, the best road possible with the material and labour and in the time available, and the more closely he can adhere to the principles of permanent civil practice the more likely is the result to be successful. The engineer officer should, therefore, study closely the progress of modern road construction and the various methods adopted in its practice in the endeavour to meet the increasing demands of traffic generally and of mechanical transport in particular. For this reason permanent roads are dealt with at some length in subsequent chapters.

He must also consider the local conditions obtaining in the country and the probable extent of enemy interference.

Equally important to a knowledge of road construction in the attainment of good results is a close co-operation with the directing authority, military or political, in order that the siting and capacity of the road may be tactically correct, and a careful organization for work so that each link in the chain may know its responsibilities and labour may not be wasted. Co-operation and organization are equally necessary in the highest and lowest formations.

In peace-time, the work which the engineer officer will undertake will be of the permanent type, and will be carried out under the general procedure described in "Regulations for Engineer Services—Peace. Pts. I and II."

Permanent roads may be required in peace-time for the development of a new country or may form part of constructional schemes for supply depots, fortresses, or barracks.

In new or undeveloped countries, or in one on the frontiers of which operations might take place, the location and character of a road will generally be determined by political or strategical and financial considerations.

The principles of the best modern practice will be followed in their construction, having regard to the country in which the work is to be carried out.

6. *Organization in the field.*

1. **Necessity for definite policy.**—A definite scheme, which has the sanction of higher authority, must be followed in all cases; the employment of men and material on any haphazard work will be futile and wasteful, and organization in procedure is of equal importance to organization of labour.

It is, therefore, essential that such schemes should be prepared in close conjunction with all branches of the staff, and with careful consideration of the requirements in each case.

All concerned should know what communications it is intended to provide before the operation commences, and their state of progress as the situation develops; this can only be effected by close collaboration between those working and those whose duty it is to direct. In large operations, the programme of road-work to be carried out by troops under the immediate orders of higher commands must be transmitted to forward commands in order that the work of the latter may be organized accordingly, so that continuity of policy may be maintained, unnecessary labour avoided, and traffic circuits arranged: this will be effected by close conference before orders are issued, when definite tasks will be allotted as appear most convenient.

Whenever several formations are taking part in an operation simultaneously, each must be in possession of the proposed scheme of work to be carried out by its neighbours as their movements may affect the work; duplication will thus be avoided.

Information regarding the enemy's roads should also be examined in order that the system may be linked with them at the earliest possible moment.

2. **Engineer organization.**—The organization for the supervision, control, and execution of road-work will vary according to the requirements of each campaign. Normally these duties will be entrusted to the engineer organizations of formations, acting within the areas assigned to each formation. But in the case of a war of great magnitude, such as that in France and Flanders 1914-19, or when road-work is on a very large scale, it may be found necessary to create a separate organization or directorate to deal with work on the main roads, which are not in close proximity to the enemy.

Should road-work be of sufficient importance, field engineers may be attached to the normal engineer staffs of formations as roads officers for special duties in connection with roads.

3. **Labour.**—The labour provided by the troops will normally be supplemented by specially enlisted military labour units, prisoners of war, and civilians. In special cases, road construction companies, composed of skilled road-workers, may be formed as units of R.E.

Road-work, especially of a permanent or semi-permanent nature, is essentially a matter for the employment of skilled labour, and such units may be depended upon to carry out the work far more quickly and efficiently than unskilled labour.

Where road-work is carried out by the troops, the normal principles relating to military labour apply. The engineer officer in charge of the work will be responsible that the work is technically correct and that the necessary tools and materials are provided; he will not be responsible for the amount of work done. He should explain the details of the work to the officer commanding the working party, and the latter will be responsible for its progress. All working parties should keep their military organization; officers and N.C.Os. should be held responsible for the progress of the work done by their companies, platoons, sections, or squads.

Task work should be given wherever possible, the smallest unit for a task being the platoon.

4. **Traffic control.**—Efficient traffic control is of great importance, not only for the movement of troops and transport but also for the maintenance of roads. Control and regulation of traffic and the provision of personnel is the province of the Q and A staff. It is greatly facilitated by the issue to all concerned of traffic maps and regulations, indicating the routes to be followed by various classes of traffic, and of any restrictions placed on the use of individual roads and bridges. Engineer officers will be responsible for the provision of an adequate number of notice boards with such indications and instructions as may be necessary.

It is particularly important to avoid serious congestion of traffic during an advance or a retirement, and to this end it may often be necessary to improve or provide deviations at difficult places. Early reconnaissance by engineer officers is essential, so that the necessary labour and material may be provided for this purpose. In dry weather, considerable lengths of cross-country tracks can be rapidly opened out; in wet weather, such deviations will normally be very limited in length, owing to the difficulty of transporting the necessary materials.

Whenever possible, sections of roads needing repair should be cleared of traffic, even for a few hours each day, so that the necessary materials may be brought to the site and the most urgent work may be carried out.

In times of thaw after severe frost, the disintegration of a road surface under heavy traffic is very rapid, and it will often be necessary to close certain roads to traffic until the effects of frost have disappeared; this will be done on the advice of the senior engineer officer present, but all orders regarding traffic are issued through the Q branch of the staff.

CHAPTER II.

RECONNAISSANCE AND SURVEY.

7. *Gradients, curves, and widths of roads.*

1. **General considerations.**—The maximum gradient permissible in a road will depend on the nature of the surface to be provided and the transport to be accommodated; no fixed rule can be laid down to govern the steepness, as gradients which would be considered excessive in flat country are common in mountainous districts. Very careful consideration must be given to the gradients when locating a new road through the latter

type of country ; neglect of this, in aiming at shortness of route, has often resulted in the requirement of new lengths of road to avoid steep hills.

The disadvantages of steep gradients are :—

(i) Loss of power.
(ii) Water from heavy rain tends to damage the surface.
(iii) Great wear and tear by animals' feet, both in ascending and descending, and indirectly fatigue to the animals themselves.
(iv) Destructive influence of brakes, slipper drags, and skidding wheels.

2. **Animal transport.**—A strong horse, weighing 1,200 lbs., can pull 1 ton at $2\frac{1}{2}$ miles per hour for 10 hours a day on a good level road, while on a smooth grade of 1 in 20 its efforts will only achieve 40 per cent. of this result, though for a short time it can exert twice its average effort ; hence the resistance on a gradient should never exceed twice that on the level. Steep slopes are very wearying to animals, producing sore backs, and are a source of delay. Long steady ascents are most fatiguing for horses and mules, while the contrary is the case with oxen. With the former, therefore, short lengths of the limiting grade with level intervals are better, while for the latter a long steady climb is preferable. Camels can work over steeper gradients than draught oxen, but cannot continuously negotiate such steep slopes as ponies, mules, or pack bullocks. Camels can, however, negotiate short lengths of very steep gradients if the road surface is dry.

In mountain roads the ascending grade rules. A man walks slowly uphill and quickly down ; a horse does the reverse—the steeper the ascent the faster will he attempt to travel until fatigued ; hence steep ascents are most trying to draught animals.

For pack tracks the conditions are reversed ; men and animals can climb steeper places than they can descend, and animals cannot retain their load down steep descents which as ascents would be quite practicable ; hence for pack transport the descending grade rules.

3. **Mechanical transport.**—In the case of motor traffic the disadvantages enumerated in para. 2 are, to a certain extent, minimized, and the question of gradient does not assume the importance attached to it when animal traction alone is considered. Motor vehicles can negotiate all hills which horse-drawn traffic is required to face, and consequently the latter only need be considered when deciding ruling gradients. The presence of mechanical transport, however, will influence the location of a road from another point of view, namely, that of maintenance. On steep hills, the wear caused by armoured tyres and steel locomotive wheels is excessive, and the gradient should be kept as flat as possible for this reason alone.

On good roads, steam wagons can carry a load equal to their own weight up a grade of 1 in 10, twice their own weight up 1 in 20, and three times their own weight on the level or up slopes not exceeding 1 in 35.

4. **Permanent roads.**—In Great Britain there is no fixed limit, but gradients should not be steeper than 1 in 20 : Telford adopted 1 in 30 as a general rule. In France and India the ruling gradient is 1 in 20, while in America 1 in 11 is not considered too steep. Wherever possible the gradient should be reduced to 1 in 35, which is the best grade for driving fast downhill and is easy to climb ; 1 in 17 is permissible for short lengths and on temporary roads, but 1 in 20 should not ordinarily be exceeded on work of a permanent nature.

In mountainous country a grade of 1 in 20 is rather too steep for continuous ascents exceeding 5 or 6 miles in length; for such, it is desirable to work to a ruling grade of 1 in 25 if possible. In dealing with these long ascents, the best practice is to arrange that the lowest portion of the climb shall be the steepest, and to provide occasional stretches of level road or halting places at intervals during the ascent for resting animals.

A longitudinal gradient of 1 in 100 to 150 is desirable for efficient drainage, and channels on level lengths of road should be given such a fall to gullies or ditches.

5. **Temporary roads.**—In forward roads during operations, it will often be necessary to save distance by increasing the gradient. The following table will serve as a guide in laying out temporary roads and tracks, but can only be consulted after due consideration has been given to the nature of the surface. It must be remembered that the force required to start a wagon moving may vary from $\frac{1}{112}$ of the load on a smooth pavement to $\frac{1}{4}$ of the load on soft earth, the figure for a macadam road being $\frac{1}{32}$. (*See* para. 6.) The figures in the columns for maximum gradient (Table A) are admissible for very short distances only.

TABLE A.—*Permissible gradients for animal transport.*

Animal.	Pack transport.		Wheel transport.	
	Maximum gradient.	Working gradient.	Maximum gradient.	Working gradient.
Horse	1 in 8	1 in 10	1 in 17	1 in 25
Pony	1 in 8	1 in 10	1 in 17	1 in 25
Mule	1 in 6	1 in 8	1 in 17	1 in 25
Camel....	1 in 10	1 in 18	—	—
Bullock	1 in 8	1 in 10	1 in 20	1 in 25

The average gradient on any mountain road should be much less than the above ruling gradients; the following figures are useful:—

1 in 40 for cart traffic.
1 in 20 for camels.
1 in 15 for other pack animals.
1 in 8 for foot paths.

6. **Resistance to traction.**—The following list gives the resistance to traction in lbs. per ton, on a level, over different road surfaces.

Surface.	Resistance to traction in lbs. per ton.
Asphalt	20
Wood paving	30
Good setts	35
Good macadam	50
Average macadam	70
Soft macadam	90
Hard, dry clay	100–110
Sand road	360
Loose earth	560

7. **Grade table.**—The following table gives the horizontal angles and vertical rises for different ratios of slope :—

TABLE B.—*Grade table.*

Inclination (tangent) 1 in	Angle with the horizon.	Rise in feet per mile.
3	18 26	1,760
4	14 2¼	1,320
5	11 18½	1,056
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	278
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 38¼	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 28½	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.*, a 4 per cent. grade = 1 in 25, 10 per cent. = 1 in 10, and so on.

8. **Curves.**—Sharp curves should seldom be allowed, except in very hilly or mountainous country ; they should not have a radius less than 60 feet except in unavoidable circumstances, when the minimum radius may be 50 feet.

Gradients on curves should be eased, but wherever possible curves should be on level ground.

9. **Width of roads.**—The width of a road depends on :—

(i) Expected traffic.
(ii) Land available.
(iii) Money available.

The average width of mechanical vehicles is approximately 8 feet; therefore, where mechanical transport has to be arranged for, the width of the road should be a multiple of 10 feet. For horse transport a multiple of 9 feet should be taken. On all single-way roads, frequent passing places must be arranged for.

For width of forward roads during operations *see* Sec. **10**, para. 2.

The Grand Trunk Roads of India are 40 feet overall—16 feet metalled (*see* Pl. **1**).

8. *Reconnaissance and survey for permanent roads in peace.*

1. **General principles governing location.**—The surveying operations undertaken in the laying out of permanent roads in peace-time will be deliberate. The question of economy will come to the fore, and there will be a definite relation between the estimated cost and the choice of route.

2. **Main ruling points.**—The demand for a road may be caused by civil requirements, by military requirements, or by a combination of both. In any case, two main ruling points will be fixed as a result of the demand, *i.e.*, the starting and finishing points, and probably several more (subsidiary), such as the positions of towns and railway stations. The order in which these points shall be linked up will probably be prearranged or obvious, otherwise a decision will usually be based on the preliminary reconnaissance (*see* para. 3).

3. **Preliminary reconnaissance and survey.**—The object of the preliminary reconnaissance and survey is the production of a report and map setting forth all reasonable main and subsidiary ruling points and all reasonable methods of connecting the same, from which one or more trial locations may be selected for detailed survey. This will often involve the reconnaissance and survey of a wide belt of country in order that no possible location may be overlooked. The procedure in reconnaissance, the matter for report, and the method of survey will depend on the following considerations.

The ruling gradient, the cost, and the reduction of the distance to a minimum as far as the natural features will permit are of prime importance.

The requirements in bridges, culverts, and other crossings will be noted. The elevations of these and of hills, saddles, passes, villages, canals, existing roads, and other important points will be fixed; the relative levels of passes and saddles should be taken with particular care. Land liable to flooding and marshy ground will be inspected and avoided if necessary. The beds of rivers and watercourses, as well as their gradients near the points of crossing, will be examined to ensure stable foundations for proposed bridges. The velocity of streams and highest flood levels should be recorded after careful enquiry, with such particulars of rainfall as may be available. The proximity of quarries of suitable stone for masonry work and for road-metal will be taken into account; in the absence of any suitable local stone the means of approach for distant supplies of material must be considered. Information should be noted regarding wells and waterholes, perennial streams, position of graveyards, attitude of natives, labour market and supplies, building materials available, &c.

In undeveloped countries the local authorities, if existent, should be consulted as to what arrangements are required regarding traffic, and for passing irrigation water across the road; if this is not done in the first instance, unforeseen extras, such as culverts and waterways, may be found necessary with a corresponding increase in the estimated cost. It is also desirable to consider the claims of traffic from neighbouring villages and towns, diverting the alignment in their direction if necessary. The extra length caused thereby will probably not add much to the cost, and may be a 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 precedence, and may cause the road to skirt native centres, to which branch roads can be constructed later. Rest houses can be built on the main road 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. To fix a camping ground near a native centre is disadvantageous as regards sanitation.

In prospecting for a road across a plain it is natural to seek to align it as direct as possible, but the monotony of a perfectly straight road should be broken. This may be done, failing natural deviation, by introducing curves, and planting trees and digging wells to hide the continuation of the road. Apart from this, the 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.

In general, all information which may be of possible use will be included in the preliminary reconnaissance, so that two or three trial lines of route may be laid down on a contoured map from which the final selection may be made.

This map should be produced by plane-tabling based on a graphical or theodolite triangulation, the contour interval being arranged to suit the nature of the relief. Very careful attention should be paid to those portions of the country in which the proposed locations approach the ruling gradient. In those sections, trial locations should be made with a clinometer, preferably the De Lisle, and these should be depicted with the greatest care on the map. It is usually preferable to test a gradient from the top of a pass downwards; if the reverse process be adopted, the surveyor will not know up which valley he should make the trial ascent. The extent to which flying levels are required should be made clear to the surveyor at the outset, and he should mark such levels in a distinctive manner on his map and leave bench marks at useful points on the ground.

When contoured maps of sufficient accuracy exist, the above remarks regarding survey should be modified accordingly.

4. **Detailed survey.**—This will usually consist of an accurate contoured traverse survey of a narrow belt, supplemented by longitudinal sections and cross-sections, and by a smaller scale plane-table survey of a broader belt. The line will be divided into sections, each in charge of a responsible subordinate, and these sections should, if possible, be bounded by ruling points.

The normal procedure of survey in each section will be as follows. A surveyor will first peg out the proposed line of the road in a series of straights, grading carefully with a clinometer and reducing his ruling gradient where necessary in order to make allowance for curves. A survey party will then follow, carrying through a detailed traverse of the pegged line with a tacheometer or theodolite, removing all the original pegs except the terminals of the straights, and fixing new numbered pegs at uniform intervals, usually 100 feet. As soon as the co-ordinates of the turning points and of convenient intervening pegs have been computed, a plane-tabler will plot them on his board to a suitable scale and will follow up the traverse party with a plane-table survey of a sufficiently broad belt, so that the relation of the traverse line to the surrounding topography may be clearly depicted. If the traverse party does not use a tacheometer, it will be followed immediately by a levelling party, which will fix the level of every peg. This party will also measure transverse slopes at every peg with a clinometer in a direction at right angles to that of the preceding leg of the traverse. If the traverse party makes use of a tacheometer, there will usually be no necessity for a separate levelling party.

The value of the principles of tacheometry is particularly demonstrated in this type of survey. The bearings for the traverse survey as well as those of subsidiary points off the line of traverse, together with their distance from the instrument and their height above it, can all be taken at one setting up, and the work of contouring the ground is thereby reduced to a minimum. Most modern theodolites have diaphragms fitted with stadia hairs, and the ordinary levelling staff may be used in conjunction with such an instrument. Chaining may also be dispensed with, provided the distance between traverse stations is not too great: 400 feet is a safe maximum figure for this distance when using a 6-inch instrument.

When a river crossing exceeds 15 feet span, it will be necessary to take two cross-sections, one above and one below the proposed crossing, and, in addition, a longitudinal section connecting the two cross-sections In the case of a rapidly flowing stream, these two cross-sections may be quite close to the bridge site, but in flat country, it may be necessary to take them sufficiently distant above and below the bridge site to enable the fall of the stream to be accurately ascertained. The distance necessary may be a mile or even more. From these two sections the volume and velocity of the water when at flood level can be calculated, and sufficient waterway at the bridge crossing must be provided accordingly.

The responsible leader of each sectional party will make notes in the field book as to the soil, rock, jungle drainage lines, sites for waterways, culverts, and bridges.

A plan drawn to a suitable scale from the survey should be kept up to date. The levels of all pegs and the measurement of transverse slopes will enable a large number of spot heights to be marked, from which the contours should be interpolated. The final result will be an accurately contoured map of a narrow belt of country in the centre of which will be marked the traverse line and pegs. This map will be supplemented by longitudinal sections and cross-sections when necessary for the computation of earthwork (*see* Secs. **12** and **13**).

The plane-table work will result in a map on a smaller scale than that of the traverse and the belt shown will be wider.

9. *Reconnaissance and survey for permanent roads during operations.*

1. **Preliminary reconnaissance.**—It is assumed that maps will be available from which information regarding the country through which the road must pass will in the first instance be obtained. The position of existing supply depots and rail-heads will be noted, and convenient sites for additional requirements in this respect taken into consideration. The important crossings and bridges will be evident.

An approximate line of route, which will often include existing cart or farm tracks which appear useful, will be laid down on a map to the scale of about 1/100,000. Having made an estimate of the requirements in labour and material, the chief engineer, after consultation with the staff, will allot sections of the route to the units at his disposal for carrying out the work, fix a ruling gradient, and call for detailed reconnaissance reports from the subordinate officers concerned.

2. **Detailed reconnaissance.**—The reconnoitring officer should first provide himself with a large scale contoured map of the area concerned; if this is not available, an enlargement must be made and the contours put in: a scale of 1/20,000 is useful for this work. He should then walk over the whole length of his section, and note any outstanding features such as streams, hills, valleys, crossings of other roads, railways, and villages; these will be considered as ruling points in the line of route.

Since time is a most important factor in the construction of this class of road, it may be found necessary to deviate from the original route in places, so as to avoid tedious work in cuttings and embankments or in providing foundations on soft and marshy ground; slight increases in the ruling gradient originally fixed are permissible if the time required for the work will be thereby reduced, but any marked deviations from the original route which are considered necessary on the ground should be immediately reported, and the reasons stated.

In country which is at all hilly, flying levels should be taken, and the route arranged so that the ruling gradient is adhered to, or only exceeded by a small margin if absolutely necessary. Sharp curves should be avoided whenever possible; if inevitable, they should be on level ground, and should not have a radius of less than 60 feet, except in very hilly country. Land subject to flooding should be avoided. The inclination of the strata on hillsides should be carefully studied in order that landslips may be guarded against. The proximity of the enemy will be taken into consideration, such areas as can be brought under the fire of his artillery avoided as far as possible, and concealment from observation aimed at.

The blockage of a road by shell fire at a critical time may have disastrous results.

The labour employed on the construction of the road will usually be able to deal with the crossing of small streams which do not present very great difficulty, and the reconnaissance report will include such information regarding these crossings as is necessary to ensure the supply of material requisite. Where a large river, navigable waterway, or railway involving extensive bridging operations has to be crossed, special troops will normally be detailed for the work. In such a case, the officer making the road reconnaissance should consult with the bridging officer in order that the approaches to the bridge may be arranged to their mutual satisfaction, since conditions affecting the banks and bed of the river will generally influence the choice of the bridge site.

The presence of villages, supply depots, or rail-heads, either existing or proposed, near the line of route will at once present the problem as to whether the road should pass through or close by them or be connected by branches. Each locality must be considered on its merits; the nature of the ground, the question of gradient, and the relative importance of the point under consideration will usually determine whether a branch or a deviation of the main road should be made. If the deviation and difference in level are not excessive, and the labour available can deal with the extra length without undue loss of time, the road should pass through or close by such important points in its first location. If, on the other hand, labour is limited, and the difference in level between the proposed route and the point concerned is considerable, it will be found expedient to pass by and construct the road on the more direct route, the village, rail-head, &c., being connected by branch roads of suitable gradient after the main road has been completed.

Longitudinal sections of the proposed route should be plotted.

The time allowed for construction will generally be limited, and will not admit of detailed surveys with trial sections being made. The amount of time necessary for location will depend on the difficulty of the country; in easy districts an officer with a good *eye for country* will usually come to a speedy decision as to the best route to take, but in difficult country the laying out will approximate more to the methods described in Sec. 8 for surveying for a permanent road in peace.

10. *Reconnaissance for forward roads, &c., during operations.*

1. **Information required.**—The value of accurate reconnaissance in forward road-work cannot be too highly estimated, and much useless labour may be avoided by a thorough knowledge of the ground to be traversed. Information will be required on the following points before any work can be commenced :—

- (i) Nature of the surface.
- (ii) Gradients anticipated.
- (iii) Obstacles to be negotiated.
- (iv) State of existing roads and bridges.
- (v) Material available locally.
- (vi) Sites for dumps.
- (vii) Freedom from enemy observation.

2. **Sources of information.**—Maps and intelligence reports, containing large quantities of very useful information concerning most probable theatres of war, should be prepared in peace-time for issue to those concerned when occasion arises.

In position warfare where it is impossible to penetrate into the enemy's lines, recent information regarding the roads in his use must be collected from air photographs, maps, intelligence reports, and the interrogation of prisoners. This will generally be carried out at the H.Q. of higher formations, where special arrangements are made for the collection of all intelligence, and its transmission by them to the lower formations for the information of all concerned.

On the other hand, under mobile conditions of warfare, much valuable additional information can be obtained by actual penetration into the enemy's lines, but the officer ordering such a reconnaissance must bear in mind the relative value of the information required and the risk entailed. Tracks and footpaths may thus be found which will often be of the greatest assistance in choosing the line of a road, as experience will have taught the inhabitants the easiest, if not the shortest, way from one place to another. The inhabitants may also be interrogated, and all local information collected.

When making a reconnaissance it should not be forgotten that, while a cross-country track only may be required in the first instance, a metalled road may take its place when the situation has sufficiently developed, and a route admitting of this is preferable. Consideration of the width of roadway intended will also influence the selection, and must be taken into account. The following are minimum figures for different types of traffic :—

(i) A width of 6 feet will suffice for infantry in file and pack transport moving in one direction, cavalry in single file, and light vehicles drawn by hand : a width of 9 feet is preferable.

(ii) A width of 10 feet, with passing places at intervals, is suitable for a one-way road for all military traffic including mechanical transport.

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

(iv) A width of 18 feet is the most economical, as this will allow mounted men and wagons to pass each other without difficulty, and two columns can pass in opposite directions.

(v) A width of 20 feet is required on all main roads carrying a continuous stream of mechanical transport and general military traffic.

(vi) A width of 24 feet is necessary for intensive double-way traffic of all classes.

Reconnaissance reports should be clear and concise, and a map should accompany them. In addition to the points enumerated in para. 1, any other information which may be of value should be included. Cross-roads and bridges should be inspected for mines and demolition charges, and any found must be immediately removed or rendered harmless.

3. **Choice of route.**—Existing roads are naturally the main consideration, since forward roads will become in most cases semi-permanent

roads and, therefore, existing facilities must be utilized to the fullest extent. The selection of an existing road as a forward road will be governed largely by an appreciation of the enemy's position and his strength in artillery. If he is equipped with long-range artillery it will sometimes be found advisable to avoid villages and cross-roads, and to aim at concealment; in such cases deviations become necessary.

If no roads exist which can be utilized as forward roads, the location of a new forward road will be governed by :—

- (i) Enemy's position.
- (ii) Enemy's strength in artillery.
- (iii) Time, labour, and material available.
- (iv) Necessity for concealment.
- (v) Necessity for avoiding villages, &c.
- (vi) Gradients.
- (vii) Obstacles.
- (viii) Its future development.

Forward tracks are required for cavalry, artillery, and pack transport.

Cavalry will require tracks along which they may advance on as broad a front as possible; these can subsequently be improved to take guns and limbers.

In position warfare, artillery will require tracks to enable them to advance across trenches or heavily shelled ground. Before an attack or an advance these should be reconnoitred jointly by the artillery and engineers. It is better, and will save time in the end, to choose a longer route which is defiladed throughout rather than a short one which is under enemy observation.

Pack transport will require tracks by which a straighter and quicker route can be obtained than that followed by wheeled transport.

In fixing the location of a forward track, the probability of its being converted into a forward road, and possibly into a semi-permanent road, must be borne in mind. It is not advisable to utilize an existing road; the track may with advantage be alongside and parallel to one which can be used by wheeled transport in wet weather.

All tracks should cross roads at right angles.

In general, no fixed rules can be laid down for selection of routes for forward roads and tracks; it will be left to the ingenuity of the officer on the spot, and his choice will depend on the conditions obtaining at the time.

11. *Reconnaissance and survey in mountainous country.*

1. **Introductory.**—The road may be either permanent or one constructed during operations. The general considerations of reconnaissance and survey will follow the lines laid down in Secs. **7**, **8**, and **9**. This section deals with matters peculiar to mountain roads, and is intended to supplement the earlier sections, and should be read in conjunction with them.

2. **Considerations of gradient.**—In mountainous country the necessity for choosing the route of a road so that the ruling gradient shall not be exceeded becomes of primary importance; the figures given in Sec. **7** may be taken as ruling gradients for the different classes of traffic. Wherever long ascents are necessary these gradients should not be increased,

and intermediate level stretches should be provided, or halting places, 40 to 50 yards long, arranged at intervals of about a mile, to rest animals during the climb. These level stretches further serve to break the drainage, and prevent an accumulation of water which would otherwise scour the surface.

3. **Geological influences.**—The dip of the strata of the rocks will influence the choice of route on hillsides; the presence of faults is also a source of danger, and these must be searched for and avoided. Pl. 2 shows the tendency to landslips which is produced by strata dipping towards the valley bottom, and also the danger caused by a fault.

Rock should be avoided as far as possible, and the engineer should select spurs and slopes which have the most soil; these will be found on the sides of mountains which are sheltered from storms. The slopes which are exposed to the prevailing winds and rain will generally be found to be rocky and bare and often entirely devoid of soil. Further, the expense of rock cutting is enormous when compared with that of earth, or earth mixed with stones.

The nature of the rock itself is important, and has a bearing on the choice of route in that the material obtained in cutting the road should generally be used in masonry work for the culverts and retaining walls, and also for road-metal.

If moraines cross a road alignment, the best arrangement is to leave their surface untouched, and to build up over them without attempting to remove the enormous boulders which frequently lie on their surface; to cut through a moraine is risky and creates a danger spot.

The sites of springs should also be examined, as these are a source of danger and subsequent disintegration.

4. **Woods and forests.**—In many cases it will be found that the slopes of valleys are thickly wooded on the one side and bare on the other. As a rule the wooded slopes are preferable, notwithstanding the increased labour required in laying out and clearing the route. Trees break the force of the rain, and the surface mould checks its flow over the road, which might, on a bare hillside, be cut away by an unchecked rush of flood water. On the other hand, the wooded portions have a greater depth of soft soil and roots, which are a disadvantage from the point of view of the road foundation.

5. **Native tracks.**—Native tracks are useful, but not always reliable in choosing a probable line; they should not be accepted as necessarily the best routes, since the application of engineering skill in dealing with obstacles may result in an improved alignment. All such tracks should, however, be carefully examined, and utilized as a base for the survey; in wooded country they are invaluable and usually safe to follow as a guide, but in thick jungle they are unreliable. As a rule, the trend of native tracks is determined by pasture and camping grounds, which must also receive consideration in the selection of the route.

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

The straightest alignment is not usually the best over hilly country. The expense of deep cuttings should only be incurred when the total rise can be reduced thereby, and there is ample time for the work.

For example, suppose A and B are two points on a proposed route with a large hill intervening, the base of which can be traversed ; the distance between A and B over the hilltop may be less than the length round the base of the hill, but the loss in power exerted in rising over the crest of the hill is obviated by a detour round the base. Hence it is permissible, as a working rule, to increase the length as much as 20 times the height saved by a detour ; thus a detour of 2,000 feet extra length is allowable to avoid a rise of 100 feet. Traffic is hindered less by an extra mile of good road than by a few hundred yards of difficult grade.

In a hill district consisting of low ranges and cultivated valleys it is best to avoid the low ground and skirt the high ground of the valley slopes, the latter being drier. By this means the watercourses are crossed higher up and nearer their source by a series of small culverts and drainage openings, while if the streams are crossed lower down the bridges necessary become troublesome and expensive, and often require embanked approaches. In other words, the aim should be to work along the watersheds ; the road may take longer and be more difficult to construct, but the cost of maintenance will be small compared to that of a road laid along a valley bottom.

In crossing a range the lowest pass can advantageously be examined first.

Sharp curves must be avoided as far as possible : 50 feet is a minimum radius of curvature for mountain roads. *Hairpin* bends are undesirable, but where they are unavoidable a clear view along the curve should be arranged whenever possible.

Zigzags.—It often happens that the opposite slopes of a watershed present very different conditions ; a gradual rise may lead to a precipitous descent, and in such a case the road must be doubled upon the spurs, or zigzags formed. Zigzags are undesirable in any alignment, except for foot traffic, or, in a special case, where it is desirable to keep a road under the protective fire of some commanding post or fort. They seldom advance progress towards the destination ; height is surmounted, but horizontal distance is not overcome. If zigzags are absolutely unavoidable suitable spots must be selected for the *turning points* which should be on level ground, and the width here increased. These obligatory points must be connected by the easiest grades possible, and the *straights* should be prolonged beyond the point of turning, in order that teams may exert a straight pull up to the level ground (*see* Pl. **3**).

When beginning the construction of the road on zigzags, it is essential that the elbows should always be commenced from their lower ends, the work being carried upwards until the straight is again reached ; by this means, a minimum of embankment is ensured, and the difficulties attendant on the construction of retaining walls at the bends will be lessened.

7. **Survey.**—A rigorous detailed survey, or even a preliminary survey, as discussed in Sec. **8**, may be considered superfluous even for a permanent road. An alternative method is to carry out a less rigorous detailed survey with a 6-inch prismatic compass and chain, but there is

no doubt that the tacheometer is peculiarly adaptable to traverse survey in mountainous country.

If it is decided that the location shall be pegged out on the ground without any preliminary survey, as might be the case during operations, this can best be effected as regards gradients with the aid of the De Lisle clinometer. This instrument gives good results with great rapidity; some of the most important and well-graded frontier roads in India were laid out entirely with it. Its advantages over other patterns of clinometer are its steadiness, as it has no bubble and quickly comes to rest, and it is little disturbed by wind and is easily read.

12. *Paper location.*

1. **Object of paper location.**—In difficult or mountainous country it is advisable, if time permits, to make a paper location of the road on the plan which has been drawn as a result of the detailed survey.

The object of the paper location will be to arrive at the best combination of straights, curves, and grades which, when laid down on this plan, will form a centre-line for the road requiring a minimum of adjustment when transferred to the ground itself. Much of the preliminary work of estimating the cost of earthwork, crossings, culverts, and other details can be based on this paper location, and may be proceeded with simultaneously, provided the detailed survey has been accurately carried out.

2. **Gradient and contour lines.**—The plan will be divided into sections, each of which will be first treated separately. Each section will be examined, and the highest and lowest points in the traverse line will be noted. From these the average gradient of the portion under consideration can be determined, and a series of straight lines drawn between the contour lines on the plan which will correspond to lines on the ground having this average gradient.

As an example, suppose the vertical interval between the contour lines is 10 feet, and the average gradient of the portion of the traverse under consideration is 1 in 30, then the horizontal distance to be traversed in order to rise or fall 10 feet at 1 in 30 is 300 feet. Set a pair of dividers to scale the distance 300 feet, and, commencing at the lowest point of the traverse line, step off this distance from contour to contour until the highest point is reached, or *vice versa*. If these points on the contour lines be joined up, the result will be an indented line having the average gradient throughout, which, if shown in section, would be represented by a straight line inclined to the horizontal at a uniform slope of 1 in 30.

3. **Adjustment in plan.**—Having drawn in this indented line at the average gradient, the next step is to find a series of straight lines and curves which will most nearly approximate to it; the amount of earthwork will depend on the amount of deviation from this line, and, by straightening it out into a series of longer lengths, a new alignment can be laid down on the plan by trial and error, which will not entail an excessive amount of work. It then remains to fit in curves to join up the straights, which may be done by finding a suitable radius for the curve between each pair of straights and drawing in the circular arcs; the minimum radius of curvature must, of course, be borne in mind.

4. **Longitudinal section.**—A longitudinal section must now be plotted along the line chosen in plan as a result of the work described above. The horizontal distances, including the length round the curves, may be measured direct from the plan, but the vertical scale should be exaggerated considerably, ten times the horizontal scale being a useful proportion. Squared paper is generally employed for plotting both longitudinal and cross-sections.

Upon this longitudinal section the line is graded; by this is meant a combination of gradients selected, all of which are flatter than the ruling gradient for the road, but which follow the ground line as closely as possible. For trial gradients stretch a black thread on the section.

This grade line will represent the formation level of the road, and will show at a glance which lengths are in cutting and which are embanked. If the earthwork entailed by the chosen line is excessive, the line must be altered in plan to reduce the earthwork, *i.e.*, it must be made to follow the indented line between the contours more closely. A new longitudinal section must then be plotted, and the line graded afresh, until eventually the best possible line will be found for the road in the section under consideration. The treatment of a section of a survey on these lines is illustrated on Pl. **4.**

5. **Junction with adjacent sections of line.**—By a similar treatment of all the sections of the plan, a paper location throughout the whole length of the road may be completed.

In difficult country, to avoid unnecessary work being caused in effecting suitable junctions between the portions of the survey treated separately, it may be advisable to work out the whole line approximately in the first instance, so as to ensure that such junctions can be readily and conveniently made, and then to proceed to consider the various portions in detail as described above.

6. **Data for pegging out.**—The positions of the pegs of the finally determined location, with relation to those already driven into the ground in the course of the detailed survey, may thus be measured from the map; their levels may be measured from the longitudinal section, and all data for pegging out the road may be written up in a field book.

7. **Alternative method of paper location.**—The use of a plane-table with a tacheometer in plotting on the ground as the survey proceeds is a very rapid way of making a paper location in the field. A sheet of transparent celluloid with arcs thereon showing the different road curves to scale is also necessary, as it enables the road to be located quickly in the field, and saves a possible revisit to the site, if a paper location be made in the office from a plotted traverse only. Squared paper should also be carried to test the profile at difficult places.

13. *Computation of earthwork.*

1. **Balancing earthwork.**—Much unnecessary labour and expense in building a new road may be avoided by the careful treatment of earthwork. The cuttings and embankments should be arranged as far as possible so that the spoil from the one may be utilized in the formation of the other. For the purpose of arriving at an approximate estimate in connection with this, the route will be divided into sections in which the balancing of the earthwork can be most economically arranged.

If a cutting and embankment are situated at a considerable distance apart, it may be more economical to form the embankment from borrow-pits, and to deposit the excavated earth from the cutting as a spoil bank, but the increased cost of acquiring an additional width of land for such purposes must not be overlooked in cases where purchase is necessary or owners have to be compensated. In addition to this balancing of cutting and embankment, the centre-line of the road should be aligned on sidelong slopes so that a cross-section can be arranged having the cutting on the one side of equal sectional area to the embankment on the other.

2. **Angle of repose.**—Each different kind of soil has its own angle of repose or natural slope, depending on the friction between the particles, within which a bank will remain stable and no slipping will occur. This angle determines the inclination of the side slopes in cuttings and embankments.

The following are useful values for the angle of repose of various materials :—

TABLE C.—*Angles of repose.*

Wet clay	0°–14°
Wet sand	25°
Vegetable soil	28°
Shingle (round)	30°
Dry sand	35°
Gravel	45°
Rubble	45°
Well drained clay	45°
Compact earth	50°

Compact rocks will stand in cuttings at steeper angles than the foregoing. Chalk, limestone, and sandstone will often stand with a vertical face provided the strata dip away from the face, but it is desirable to give the sides of all rock cuttings an inclination of at least 2 in 1, in order that a wet road surface may be well exposed to the drying action of wind and sun.

3. **Calculations.**—On short lengths the approximate method, viz., to take a mean between the end sectional areas, will suffice for all practical purposes, but will always give more than the true contents.

Where a large number of sectional areas have to be computed Amsler's Planimeter will be found very useful, but if this instrument is not available the areas can be quite accurately determined by plotting on squared paper. Where drawing office methods cannot be employed, and a rapid computation is required, formulæ may be resorted to.

The *prismoidal formula* gives good results for cubical contents on regular ground, and is :—

Volume $= \frac{1}{6}$ of length $\times$ (sum of 2 end areas $+$ 4 times the middle area).

Pls. 5 and 6 show various types of cross-section commonly met with, and the formula for determining the sectional area is given in each case.

It is a great saving in time and more conducive to practical accuracy if the computation of earthwork can be carried out in the field simultaneously with the tracing and alignment; the nature of the soil can be recorded for each case, and the work estimated and priced on the spot.

4. **Setting out on sidelong slopes.**—A method for determining the cutting edges on the ground, which is sufficiently accurate for all practical purposes, is illustrated on Pl. **6**, Fig. 2. The procedure is as follows:—Lay off the road width and side slopes, when in bank or cutting or both, on the plotted cross-section, and compute the area of the half-breadths. The positions of A and B can then be obtained on the ground by trial and error with a level and staff. Assume an approximate position for the point A, and find the difference in level between A and C; multiply this difference by the ratio of the side slopes, and subtract the result from the computed area of the half-width. If the remainder is equal to the distance of the staff from the centre-line, the assumed position for A is correct, otherwise repeat this procedure until the point A is correctly fixed. If the remainder exceeds the distance of the assumed point A from the centre-line, then A is too near, and *vice versa*. The point B can be found in a similar manner.

In the case of an embankment the same method will suffice.

5. **Setting out mountain tracks.**—The *slope templet* (*see* Pl. **6**, Fig. 3), for setting out the estimated back slope, on which the area of the cross-section so largely depends, has been found very useful when prospecting for pack roads in hill districts, and has been found particularly valuable in arriving at the comparative probable cost of alternative alignments. It does away with the necessity for taking cross-sections, and furnishes a simple means of recording the amount of excavation required, especially for narrow roads on steep slopes.

The templet consists of a stout vertical batten ($2\frac{1}{2}$ inches $\times$ 2 inches) graduated in feet, and provided at the foot with a hinged or knuckle joint into which is fitted a long light bamboo arm. To this arm a wire is attached, which passes over a pulley on the vertical batten and ends in a ring for hooking over screws or cleats, fixed to the batten, so that the arm may be set at a given slope of 1 in 1, 1 in $1\frac{1}{2}$, &c., up to 1 in 4 or 5.

It is used as follows:—It is assumed that the cutting-line has been marked out with a clinometer, and that chaining is commenced from the top. The templet is set up by one man of the computing party on the spot fixed by the back chainman. A second man standing on the slope above the templet, carries a long straight bamboo marked at 4, 6, and 8 feet from one end (*i.e.*, the widths of cuttings), which he grasps with one hand at the mark given (in mule tracks usually 8 feet width for a full cutting), and, holding it high and horizontal, places the same hand against the movable arm of the templet. He then slides his hand down the movable arm, keeping the bamboo horizontal, until the end touches the ground. This will be the point for the inner cutting-line, if the arm of the templet has been set at the required slope. The height at which the horizontal bamboo meets the vertical batten of the templet is read off and recorded.

The area of the cross-section can then be calculated, and the cubical contents entered in the field book at each chain length or less, the volume recorded being the amount of excavation required between that and the preceding chain point. It then only remains to total, abstract, and price the quantities at the end of each day.

The field book is ruled thus :—

TABLE D.—*Example of field book using slope templet.*

Chain (100 feet).	Back slope.	Width (feet).	Height (feet).	Sectional area of cross-section. Square feet.	Soil in cubic feet.				Remarks.
					Hard.	Medium.	Soft.		
Brought forward			....	....	10,270	18,980	25,460		
19	3/1	8	6	24	—	2,400	—		
20	2½/1	8	4	16	—	—	1,600		
21	3/1	8	8	32	1,600	1,600	—		Spur at 21·8. Allow 2 feet bank.
22	2/1	6	5	15	—	—	1,500		
Carried forward			....	....					

In the remarks column, entries can be made where streams are crossed, length of Irish bridges or culverts, &c., and any special points regarding the soil and excavation required. Sufficient accuracy can usually be obtained by dividing the work and prices into *hard*, or soil requiring blasting, *medium*, or soil requiring blasting and jumper work, and *soft*, or pick-and-jumper work.

14. *Preliminary alignment.*

Having determined as nearly as possible the correct centre-line for the road by means of a paper location (Sec. **12**), it is necessary to transfer this line to the ground, both in order that its suitability may be tested and that preparations for the work of construction may be made.

No road should ever be commenced until the trace is cut through ; it is often tempting to disregard this when time presses, but to do so is not sound practice.

A clearing party pegs out the line by eye, using a De Lisle clinometer or Abney level. In a jungle they will blaze trees, and a passage will be cut ; in tall elephant grass a step-ladder will be required. Labour gangs will follow, and cut a path 18 inches or 2 feet in width along the final pegged alignment.

In lining out a hill road with steep gradients it is best to commence at the top of the slopes. Hills and mountains are usually steeper towards their summits, and there is less choice of line than lower down, so that, if the gradient is commenced at the foot of the slope, the surveyor, on arrival at the steepest portion of his alignment, may find that the horizontal distance must be considerably increased if the ridge is to be crossed without any unfavourable departure from the ruling gradient, and is, therefore, forced to introduce the zigzag alignment, or discard his previous work and commence afresh. Therefore, it is better to traverse down from the passes and up from the bridge sites, and to note by eye the points on the hillsides, especially at salients, which the maximum grade line will cut ; the road will then not exceed the ruling gradient.

In laying out by forward shots along the ins-and-outs on sidelong ground, it must be borne in mind that the original trace of curves must be laid out considerably easier than the gradient intended for the finished road. The allowance to be made varies with the nature of the ground, but in general 1 in 37 will work down to 1 in 35, and 1 in 22 down to 1 in 20. It is a sound plan in laying out to conform to the surface gradients as much as possible.

Whitewash and red paint are useful in tracing over rock, and prominent and distinct bench marks are always necessary.

In opening the first path or track where very difficult cliffs occur in the line of route, temporary tracks may be made either above or below the proposed alignment, but after passing the obstacle it is important that the proper level is immediately regained. By this means a through passage can be obtained long before the permanent route could be opened out at the intended level.

When actually cutting the alignment it is desirable to start with a narrow pathway, and peg out every 100 yards, at least, throughout the length; one peg should be driven in the centre of the road (finished breadth) and covered over for later use, another being driven at the side of the road to enable the first to be found.

On level ground the boundaries should be spitlocked; on sidelong slopes the outer cutting-line only should be marked, and excavation should proceed inwards and not downhill from the cutting-line on the hillside. A very careful check must be kept on level pegs, and they should be replaced by supplementary bench marks whenever they have to be removed.

When laying out round spurs the outer half of the road should be banked up, and given sufficient elevation over the inner half to assist vehicles in turning, and to promote safety, especially for fast-moving motor traffic when proceeding downhill. When guns have to be transported, the roadway must be widened at all curves to allow for the increased length of track due to trail and limber.

The detailed survey for bridges, culverts, retaining walls, and curves may be carried out, however, after the work of clearing has begun. It is of great importance to get a 4-foot, or even a 1-foot, pathway right through as soon as possible, which can be increased to the required width after the construction gangs have been allotted their tasks. In sidelong ground where the road must be entirely banked up, the foundations for retaining walls should be laid out and commenced as soon as possible.

15. *Setting out curves.*

1. Alternative methods.—In setting out the centre-line of a road round a curve, the work will not be required to reach that degree of accuracy which is necessary in the location of a railway line. The curves will be simple arcs of a circle in all cases, and the introduction of transition curves between the straight and the circular portions can be dispensed with.

For long curves the use of the theodolite will be necessary, and in some cases two instruments may be employed, one being set up at either end of the curve. The method employed will depend on whether there is a clear view along the curve and along the line of the *straights*, and also if the point of intersection of the latter is accessible.

In mountainous country or densely wooded areas angular instruments cannot be used, and the chain or steel tape alone must be resorted to, the procedure adopted being known as the *method of offsets*.

The method of offsets may also be used in setting out all short curves on roads, and the work will generally be carried out more rapidly than is possible when the theodolite is employed, although the degree of accuracy attained is not so high, and the pegs will often be finally aligned by eye.

2. **Properties of circular curves.**—Before describing the methods adopted in setting out circular curves on the ground by means of the theodolite, it is necessary to refer briefly to the properties of these curves, upon which the procedure is based.

Equal chords subtend equal angles at any point in the circumference of a circle, and, further, such angles are each equal to half the angle subtended at the centre by the same chord. Also, the acute angle between a tangent and a chord is equal to half the angle subtended at the centre by that chord. Therefore, referring to Pl. 7, Fig. 1, if TB is a tangent to the circle with centre O and radius r, and BC is a chord of length x, then $T\hat{B}C = B\hat{P}C = \frac{1}{2}B\hat{O}C$.

It is obvious that to find the point C on the circumference of a circle, knowing the values of r and x, the instrument must be set up at B, the tangent point, and be turned through the angle TBC after having calculated its value. This angle is called the *deflection angle* for the chord BC.

Now the angle subtended at the centre of a circle by an arc equal to the radius is 1 radian, or 57·3 degrees. Therefore the angle subtended by a chord of length x, which may be considered equal to the short arc BC, is equal to $\frac{x}{r}$ radians,

$$i.e., \ B\hat{O}C = \frac{x}{r}\text{ radians} = \frac{x}{r} \times 57{\cdot}3 \times 60 \text{ minutes},$$

$$\text{but } T\hat{B}C = \tfrac{1}{2}B\hat{O}C = \frac{x}{r} \times 57{\cdot}3 \times \frac{60}{2} \text{ minutes}$$

$$= 1{,}719\ \frac{x}{r} \text{ minutes.}$$

In other words, the deflection angle in minutes between a tangent and any chord is equal to $1{,}719 \dfrac{\text{length of chord}}{\text{length of radius}}$.

This formula is used in calculating all deflection angles when setting out circular curves.

3. **Length of chords.**—The above formula is based on the assumption that the length of an arc is equal to that of the chord on which it stands, and the resulting deflections are, therefore, burdened with certain errors. Moreover, the through chainage is effected along these same chords, and is also burdened with similar errors. In order to minimize the effect of these errors, it is customary on sharp curves to work with chords of half a chain length or less.

4. **Point of intersection accessible.**—Referring to Pl. 7, Fig. 2; suppose SA and $S'A$ are two straight portions of the centre-line of the road intersecting at A: it is required to connect these two *straights* by a circular arc BC of radius r feet. It is possible to set up the instrument

over the point A and to sight back along each straight in this case, and the first operation necessary is the fixing of the terminal points of the curve, B and C, on the ground ; these points are called the *tangent points*, and the distances AB and AC the *tangent lengths*. The lengths AB and AC are obtained by setting up the instrument over the intersection point A, and carefully measuring the intersection angle BAC. If this angle $= a$,

$$\text{then } AB = AC = r \cot \frac{a}{2}.$$

These calculated distances are then measured off along the straights, and substantial pegs are driven at B and C.

The instrument is then set up on the point B or C, say B, and the point A is sighted with the vernier at zero. The deflection angle for the whole curve, which is equal to $90 - \frac{a}{2}$, is then turned through, and the point C is checked.

The setting out of the intermediate points B^1, B^2, B^3, &c., may then be commenced. These points should be located at equal intervals, say of 1 chain, along the arc (*see* preceding para.), but, since through chainage is essential, the distance BB^1 will be less than 1 chain in length, and, if O is the last chain point on the straight, then $BB^1 = 1$ chain $- OB$, and the deflection angle for the chord BB^1 will be $1{,}719\frac{BB^1}{r}$ minutes (*see* para. 2). By turning the instrument through this angle, and at the same time directing the chainman to keep the portion BB^1 of his chain tight, a peg may be driven at the point B^1.

The chaining may then be continued, and the second peg at point B^2 may be located by turning the instrument through an angle equal to $1{,}719\frac{BB^1 + 1 \text{ chain}}{r}$ minutes. Similarly all the remaining points may be located, and finally, after driving the last peg at point B^7, by adding to the deflection angle for this peg the calculated deflection angle for the remaining fraction of a chain, B^7C, the point C may again be checked.

The pegs as first located should not be driven home ; any error that may be discovered on reaching the end of the curve, provided it is not of such magnitude as to require a fresh setting out, may be adjusted in the final chaining.

5. **Point of intersection not accessible.**—The difference between this case and that described in the preceding paragraph is due to the fact that, since the instrument cannot be set up over the point A, other means have to be employed in order to locate the points B and C, and to measure the angle a (*see* Pl. 7, Fig. 3).

Points D and E are selected on the straights, and a straight line is ranged between them. The angles BDE and DEC are then measured. Call these angles δ and ϕ respectively,

$$\text{then angle } a = \delta + \phi - 180°,$$

$$\text{and } AD = DE \frac{\sin \phi}{\sin a},$$

$$\text{also } AE = DE \frac{\sin \delta}{\sin a}.$$

In mountainous country or densely wooded areas angular instruments cannot be used, and the chain or steel tape alone must be resorted to, the procedure adopted being known as the *method of offsets*.

The method of offsets may also be used in setting out all short curves on roads, and the work will generally be carried out more rapidly than is possible when the theodolite is employed, although the degree of accuracy attained is not so high, and the pegs will often be finally aligned by eye.

2. **Properties of circular curves.**—Before describing the methods adopted in setting out circular curves on the ground by means of the theodolite, it is necessary to refer briefly to the properties of these curves, upon which the procedure is based.

Equal chords subtend equal angles at any point in the circumference of a circle, and, further, such angles are each equal to half the angle subtended at the centre by the same chord. Also, the acute angle between a tangent and a chord is equal to half the angle subtended at the centre by that chord. Therefore, referring to Pl. 7, Fig. 1, if TB is a tangent to the circle with centre O and radius r, and BC is a chord of length x, then $T\hat{B}C = B\hat{P}C = \frac{1}{2}B\hat{O}C$.

It is obvious that to find the point C on the circumference of a circle, knowing the values of r and x, the instrument must be set up at B, the tangent point, and be turned through the angle TBC after having calculated its value. This angle is called the *deflection angle* for the chord BC.

Now the angle subtended at the centre of a circle by an arc equal to the radius is 1 radian, or 57·3 degrees. Therefore the angle subtended by a chord of length x, which may be considered equal to the short arc BC, is equal to $\frac{x}{r}$ radians,

$$i.e.,\ B\hat{O}C = \frac{x}{r}\text{ radians} = \frac{x}{r} \times 57\cdot3 \times 60 \text{ minutes},$$

$$\text{but } T\hat{B}C = \tfrac{1}{2}B\hat{O}C = \frac{x}{r} \times 57\cdot3 \times \frac{60}{2} \text{ minutes}$$

$$= 1{,}719\,\frac{x}{r} \text{ minutes}.$$

In other words, the deflection angle in minutes between a tangent and any chord is equal to $1{,}719\,\frac{\text{length of chord}}{\text{length of radius}}$.

This formula is used in calculating all deflection angles when setting out circular curves.

3. **Length of chords.**—The above formula is based on the assumption that the length of an arc is equal to that of the chord on which it stands, and the resulting deflections are, therefore, burdened with certain errors. Moreover, the through chainage is effected along these same chords, and is also burdened with similar errors. In order to minimize the effect of these errors, it is customary on sharp curves to work with chords of half a chain length or less.

4. **Point of intersection accessible.**—Referring to Pl. 7, Fig. 2; suppose SA and $S'A$ are two straight portions of the centre-line of the road intersecting at A: it is required to connect these two *straights* by a circular arc BC of radius r feet. It is possible to set up the instrument

over the point A and to sight back along each straight in this case, and the first operation necessary is the fixing of the terminal points of the curve, B and C, on the ground; these points are called the *tangent points*, and the distances AB and AC the *tangent lengths*. The lengths AB and AC are obtained by setting up the instrument over the intersection point A, and carefully measuring the intersection angle BAC. If this angle $= \alpha$,

$$\text{then } AB = AC = r \cot \frac{\alpha}{2}.$$

These calculated distances are then measured off along the straights, and substantial pegs are driven at B and C.

The instrument is then set up on the point B or C, say B, and the point A is sighted with the vernier at zero. The deflection angle for the whole curve, which is equal to $90 - \frac{\alpha}{2}$, is then turned through, and the point C is checked.

The setting out of the intermediate points B^1, B^2, B^3, &c., may then be commenced. These points should be located at equal intervals, say of 1 chain, along the arc (*see* preceding para.), but, since through chainage is essential, the distance BB^1 will be less than 1 chain in length, and, if O is the last chain point on the straight, then $BB^1 = 1 \text{ chain} - OB$, and the deflection angle for the chord BB^1 will be $1{,}719 \frac{BB^1}{r}$ minutes (*see* para. 2). By turning the instrument through this angle, and at the same time directing the chainman to keep the portion BB^1 of his chain tight, a peg may be driven at the point B^1.

The chaining may then be continued, and the second peg at point B^2 may be located by turning the instrument through an angle equal to $1{,}719 \frac{BB^1 + 1 \text{ chain}}{r}$ minutes. Similarly all the remaining points may be located, and finally, after driving the last peg at point B^7, by adding to the deflection angle for this peg the calculated deflection angle for the remaining fraction of a chain, B^7C, the point C may again be checked.

The pegs as first located should not be driven home; any error that may be discovered on reaching the end of the curve, provided it is not of such magnitude as to require a fresh setting out, may be adjusted in the final chaining.

5. **Point of intersection not accessible.**—The difference between this case and that described in the preceding paragraph is due to the fact that, since the instrument cannot be set up over the point A, other means have to be employed in order to locate the points B and C, and to measure the angle α (*see* Pl. 7, Fig. 3).

Points D and E are selected on the straights, and a straight line is ranged between them. The angles BDE and DEC are then measured. Call these angles δ and ϕ respectively,

$$\text{then angle } \alpha = \delta + \phi - 180^\circ,$$

$$\text{and } AD = DE \frac{\sin \phi}{\sin \alpha},$$

$$\text{also } AE = DE \frac{\sin \delta}{\sin \alpha}.$$

But, as before, $AB = AC = r \cot \frac{a}{2}$, from which DB and EC may be calculated, and the points B and C located on the ground. The procedure is then similar to that described in the preceding paragraph.

If the straight line DE cannot be chained, a traverse must be run between the two points in order to obtain the angles δ and ϕ.

6. Method of offsets.—This method is extremely useful for the rapid setting out of short curves, and is the one usually employed in road-work.

The angle of intersection between the straights will generally have been obtained when running the traverse survey, so that the tangent lengths can be calculated and the tangent points B and C (Pl. 8, Fig. 1) fixed. The chain and steel tape can then be used to fix the intermediate points on the curve of radius r; any error which may be found on arriving at the second tangent point C can usually be adjusted by eye.

The following is the method of locating the intermediate points E, G, J, L, &c. As before, the tangent point B will seldom coincide with a chainage point on the straight. Suppose O is the last peg on the straight before B is reached, and OD the next chain length on the straight, a peg is driven at the tangent point B, and the portion of the chain BD is swung through an angle DBE such that

$$DE = \frac{(BD)^2}{2r}.$$

This distance, or offset, DE having been calculated, the point E may be fixed by a manipulation of the chain and the steel tape, and the first point on the curve is fixed.

The chaining is then continued along the line BE which is produced to F, where EF is equal to the chosen chord, usually one chain in length except on sharp curves, when it may be as small as convenient.

The end of the chain at F is then swung to G, the offset FG having been obtained by calculation :—

$$FG = \frac{BF \times EF}{2r}.$$

This fixes the next point G on the curve, and the remaining points are obtained by a repetition of this process, the offset in each case being $\frac{c^2}{r}$ where c is the full chord length.

If the tangent point B coincides with the last chainage point on the straight, the first offset must be taken as one half of whatever is accepted as the normal offset.

7. Method of finding tangent lengths without an angular instrument.—The method of fixing the tangent points of a curve of small radius without the use of a theodolite is useful, and may be employed in conjunction with the setting out by the *method of offsets*.

Referring to Pl. 8, Fig. 2, let SA and $S'A$ be the two straights or tangents which it is required to connect with a circular curve of given radius.

Produce SA to D, making AD a definite fraction of the radius of the curve, set off AE equal to AD, join DE, and bisect it at F. At D set off DG perpendicular to AD and meeting AF produced in G. Then DG will be the same fraction of the tangent length required as AD is of the radius, and will enable the tangent points to be fixed.

If DE is equal to $1 \cdot 4142 \times AD$, the angle of intersection is a right angle; with a smaller angle DG becomes inconveniently long, and the following alternative method, illustrated on Pl. **8**, Fig. 3, may be used. Equal lengths SA and $S'A$ are set off on the two straights, SS' is bisected at D, and at either S or S', say at S, SE is set off perpendicular to SA meeting AD produced in E, and measured. Then the required tangent length is equal to $\frac{SA \times radius}{SE}$.

These methods may be employed graphically for small curves in road-work, provided a sufficiently large scale is used.

CHAPTER III.

THE PRINCIPLES OF ROAD CONSTRUCTION.

16. *Introductory.*

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 is necessary, apart from the study of principles.

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

As far as possible a road must offer a hard smooth surface to traffic, and to attain this the following *essentials* are necessary:—

(i) It must be efficiently drained and kept dry, otherwise it will become soft, *i.e., Drainage.*

(ii) The ground on which the foundations of a road will rest must be well prepared, drained, and consolidated, otherwise the road will sink and remain no longer smooth and level, *i.e., Formation.*

(iii) The foundation on which the surface of the road will rest must be firm, otherwise the road surface will sink and remain no longer smooth and level, *i.e., Foundations.*

(iv) The surface material must be hard enough to resist rapid wear, otherwise the surface will become uneven, *i.e., Surface.*

From the foregoing it follows that the four main *principles* of road construction concern:—

(i) **Drainage.**
(ii) **Formation.**
(iii) **Foundations.**
(iv) **Surface.**

These principles will be discussed in Secs. **17, 18, 19,** and **20** respectively.

17. *Drainage.*

1. The drainage system of a road comprises :—

(i) Drainage of the formation.
(ii) „ foundation.
(iii) „ surface.
(iv) „ ground in the vicinity.

(i), (ii), and (iii) are discussed in Secs. **18, 19,** and **20,** which deal with the formation, foundation, and surface.

The drainage of the ground in the vicinity of a road and also the collection and disposal of the drainage from (i), (ii), and (iii) is carried out by two longitudinal side drains or ditches, one on each side of the road (*see* Pl. **9**).

Ditches should be from $2\frac{1}{2}$ to 3 feet in depth, and the bottom should not be less than 1 foot below the formation level. Care should be taken to prevent the sides from falling in, and, if sufficient slope cannot be given to them when cutting the ditch, or the proximity of the road is such that pressure from traffic may be liable to cause slipping, timber revetment or stone pitching must be used. In country roads, ditches, which should not be nearer the edge of the road than 6 feet, should be dug at the roadsides, preferably beyond the boundary fences or hedges where these are close to the haunches. If it is necessary to place a ditch nearer than this, and there is a danger of vehicles getting into it, a slab drain may be constructed and covered with stones and brushwood ; such a drain is termed a *blind drain* (*see* Pl. **12**, Fig. 5).

2. The interception of water from the slopes of cuttings and on sidelong, *i.e.*, sloping, ground is carried out by means of *catch-water drains* cut on the uphill side of the road, in addition to the side drains. Each site must be dealt with on its merits ; an example of such treatment is shown on Pl. **10**.

If possible catch-water drains should discharge direct into the nearest watercourse. Where this is not practicable they may be connected to the side drains at intervals, but, if this is done, care should be taken that the sides of the slope are not damaged by the rapid flow of water from the catch-water drain to the side drain below. Stone-pitched channels should be provided, or drain-pipes built into the slope.

3. In towns and thickly populated areas where sewerage systems are installed, the gullies and gutters will connect with the system, and the sewers must be made capable of dealing with the maximum rainfall anticipated in addition to the sewage, or separate surface water sewers provided.

18. *Formation or subgrade.*

1. The necessity for the proper treatment of the ground before the foundation of a road is laid is not always realized. A careful study of the subsoil to determine the amount of drainage and consolidation that will be required must be made in all cases, and much valuable time, labour, and material may be wasted if the preliminary work on the subgrade has been neglected.

To lay the foundation of a road on a badly drained or weak formation will result in settlements and subsequent breaking up of the road surface ;

these defects will become very apparent during periods of alternate frost and thaw, when water imprisoned in the foundation of a road will cause rapid disintegration.

2. **Subsoils** may be roughly divided into three classes; namely, permeable, impermeable, and solid rock.

Permeable subsoils will in general be of a sandy or gravelly nature, and will not give rise to much difficulty in the construction of the subgrade; any water which finds its way into them will percolate through to the side drains.

Impermeable clay soils, on the other hand, require very careful treatment. Water does not percolate through them, and must be drained off as rapidly as possible. If a clay formation is allowed to become waterlogged it will quickly be transformed into mud, which will work up through the road foundation under the pressure of traffic and destroy it. Over a clay formation a layer of permeable material is, therefore, added to act as a seal, and so prevent mud working up through the foundation of the road.

As a rule, a rock formation will not give trouble as regards drainage, but the consolidation of the road-metal over it requires careful execution, as there will be a tendency for the stones to be pounded up before they can bind together, and, to alleviate this, it is necessary that a cushion of sand or clinker at least 6 inches thick should be laid over the rock before the road foundation is put down.

3. **Drainage of formation.**—The methods employed to carry off water which has found its way into the road-bed will vary according to the nature of the soil and the slope of the ground, and each case must be treated to a certain extent on its merits.

Particular attention to subdrainage must be given on lengths of road so situated that the natural drainage of the surrounding country is intercepted; in such cases, to avoid a permanently wet subsoil, the road-bed must be kept free from water by an arrangement of drains which will carry it off to the side ditches.

In the case of a subgrade formed on flat ground where there is no definite direction of flow, the longitudinal ditches on either side of the road will suffice in gravelly or porous soil, but if the ground is of impermeable clay it will be necessary to cut transverse drains beneath the road and to connect these with the side ditches. Pl. **11**, Fig. 1, shows this principle. The cross-drains must be laid 15 to 18 inches below the formation level, and should be given a fall of about 1 in 50, and the depth of the side ditches must be arranged accordingly. The distance apart of the transverse drains depends on the nature of the subsoil; in the heaviest types of clay soil they may be required at intervals of every 12 to 20 feet, while in lighter soils they may be as much as 50 feet apart.

In clay soil, the formation may be more easily prevented from becoming water-logged by draining the surface of the finished roadway by means of channels and gutters than by subdrainage.

On sidelong slopes, where the direction of flow is well defined, the side ditch on the uphill side of the road, as on Pl. **11**, Fig. 2, will suffice, provided a catch-water drain is cut at the top of the bank; the water from this side ditch may be carried under the road by means of small culverts at intervals, and drained on to the low ground.

In cuttings where there is not sufficient room for side drains a longitudinal central drain may be used, as shown on Pl. **11**, Fig. 3; this central drain should be connected to the side drains when clear of the cutting.

To form such covered drains, small trenches should be cut and given the required fall; round pebbles should then be packed in the bottom of the trench and covered with gravel. Angular stones should never be used in drains, as they will pack too closely and leave no interstices through which the water can percolate. If available, ordinary agricultural tile drain-pipes may be laid in the trenches with open joints; they should be packed with pebbles and gravel. Box-drains may be laid in gravel in a similar manner if suitable stone slabbing is available. Pl. **12** shows different varieties of covered drains used in road drainage.

4. **Consolidation of formation.**—The formation on which the foundation of a road will rest should be raised and of the nature of a **bank**, which can usually be formed of the soil excavated from the side drains. This bank will raise the general level of the formation above the adjoining ground (except in cuttings where, however, the principle will still apply), and so assist to keep the road "high and dry."

Every road should be a watershed and not a watercourse, and, therefore, the tendency to dig a canal and place the foundation in it must be strictly guarded against (*see* Pl. **9**).

In all cases this formation or bank must be made compact before any foundation is put on it. It will generally be necessary to employ a heavy roller to obtain this compactness, and to continue rolling until no impression is made. On a clay soil, clinker, sand, or chalk should be added and rolled to a thickness of at least 6 inches to act as a seal.

It is generally advisable that the formation or bank should be consolidated with the camber which will be required by the finished surface.

19. *Foundation.*

1. The foundation is placed between the road surface and the subgrade in order that the pressure produced by traffic on the latter may not reach such an intensity as to cause subsidence and consequent disintegration.

The conditions required in a good foundation may be briefly enumerated as follows:—

(i) It must be strong enough, and of sufficient elasticity, to bear the pressure of the traffic without permanent displacement or crushing.

(ii) It must be thick enough to distribute the pressure over the subgrade, so that the latter is not stressed beyond its elastic limit.

(iii) It should be permeable enough to permit water to drain through it to the subgrade.

The following foundations have been found to comply with the above conditions:—

(*a*) Large stones for macadam roads and for certain types of paved roads, such as stone setts; this type is known as the Telford foundation (*see* Secs. **22, 23,** and **52**).

(*b*) Strong timbers for corduroy and plank roads, by means of which a raft is formed to distribute the pressure due to traffic (*see* Sec. **29**).

Concrete is now generally used as a foundation for most types of paved roads and streets (*see* Chap. IX). It fulfils the conditions of (i) and (ii), but not of (iii), as explained in para. 2.

In very soft ground it is often necessary, in addition, to use fascines or some similar material to stabilize the foundation, and to assist the distribution of traffic pressure on the formation.

2. **Drainage of foundation.**—The large stones in macadam roads and the timber raft in corduroy and plank roads facilitate the drainage of these types of foundation. Thus water which has percolated from the surface down to the foundations will easily find its way through these types to the formation from which it will be drained (*see* Sec. **18**).

Concrete foundations are impervious to water, and, as the surfaces of those types of paved roads in which they are used are similarly impervious, no water should percolate through to the foundations.

20. *Surface.*

1. The essential requirements of a good road surface, which must be borne in mind when selecting the material and deciding on the method of its application, are :—

- (i) It should provide a hard smooth surface for traffic.
- (ii) It should provide a waterproof covering for the road.
- (iii) It should furnish a wear-resisting medium for the protection of the foundation beneath it.

The extent to which the materials used in the surface structure of various types of road comply with the above requirements will now be shown :—

(*a*) Small hard insoluble stones used for macadam roads comply with (i) and (iii) and to a certain extent with (ii). If, however, the surface material is properly graded and consolidated, if sufficient camber is given to the road surface to enable surface water to quickly drain off to the side drains, and if the road is properly maintained, very little water will percolate through to the foundation (*see* Sec. **23**).

The addition of a surface coating of tar to this type of material will make it temporarily comply with (ii) (*see* Sec. **26**, para. 3).

(*b*) Round, half-round, or flat timber used in corduroy or plank roads complies with (iii), to a certain extent with (i), and not with (ii) (*see* Sec. **29**).

(*c*) Tarred small hard stones used in tarred macadam roads and asphalt, concrete, wood blocks, and properly grouted stone setts used in paved roads comply with (i), (ii), and (iii) (*see* Sec. **24** and Chap. IX).

2. **Drainage of surface.**—Rain-water falling on the surface of a road is made to run off into the drainage system at the sides of the road (Sec. **17**)

by means of a camber which is given to the surface ; the rougher the surface the greater the camber should be. For a water-bound macadam road the camber is usually 1 in 24 to 1 in 30 of the width of the roadway ; if the centre is given a greater elevation than this, there is the danger of skidding. For smoother surfaces the camber can be reduced, *e.g.*, stone setts 1 in 36, wood paving 1 in 42, asphalt 1 in 48.

A certain amount of rain-water will find its way through road surfaces constructed of materials mentioned in para. 1 (*a*) and (*b*) ; the drainage of such rain-water is dealt with in Sec. **19.**

21. *Cuttings and embankments.*

1. The necessity for cuttings and embankments will arise in the endeavour to provide easy gradients, and the magnitude of such works will generally be governed by the ruling gradient adopted.

The line of the road will be determined in accordance with the methods described in Chap. II ; the lengths of cutting and embankment required are immediately apparent if a line representing the formation level of the road is drawn through the longitudinal section.

Embankments are often necessary in forming the approaches to bridges over waterways or railways where considerable headroom has to be maintained ; they are also resorted to in order to carry roads over marshy ground or land subject to flooding.

2. **Cuttings.**—It is advisable that small trial pits be sunk at intervals along the line of cutting, in order to obtain information regarding the soil and to determine the slope at which the sides will stand. The provision of retaining walls at the foot of the slopes may be necessary in deep cuttings through unstable material, but in safer soils the laying of turf or sowing of grass seeds will suffice to counteract the action of weather.

In excavating for a cutting without the aid of mechanical excavators, the most convenient method of removing the spoil is to dig small trenches along the cut-lines at ground level on each side, and to take off the soil in layers of about 1 foot in depth, commencing each layer 1 foot nearer the centre-line at each side. By this means stepped sides will be formed, which can be dressed to the required slope when the formation level is reached. If curves occur in a cutting, the slope of the sides should be decreased or ledges cut in order to improve the view round the curve and thus reduce the danger of collisions.

A gentle gradient should always be given to a road throughout the length of cutting for the purposes of surface drainage.

Spoil banks will have to be formed if the spoil cannot be used in a neighbouring embankment. They should be on low ground, and situated away from the side slopes in order that they may not cause slipping through additional weight or surcharge. The tops of spoil banks alongside a cutting should slope away from it, otherwise surface water from them will drain into it.

Slips must be guarded against in loosely stratified rock or shale, and in deep cuttings careful drainage by catch-water drains set well back from the top of the cutting is necessary. The slopes should also be drained at intervals by rubble drains or earthenware pipes with open joints.

The sides of deep cuttings in bad ground may be benched with advantage, and the terraces thus formed should be given a longitudinal gradient parallel to that of the road, and a cross-fall towards the hillside with gutters similar to those on the roadside.

3. **Embankments.**—The slope given to the sides of an embankment will depend on the nature of the soil and its angle of repose (*see* Sec. **13**). Embankments should be limited in height as much as possible, and great care should be exercised in their construction.

Borrow-pits must be resorted to if material from cuttings cannot be economically employed. They should not commence within 10 feet of the toe of the bank, and, provided land is available, their depth at the inner edge should not be more than 1 foot, increasing by 1 foot at every 5 feet distance outwards. In tropical regions borrow-pits are apt to become insanitary, and should be filled in with suitable material when available; they should not be excavated in the proximity of dwellings, as when full of stagnant water they form a breeding place for mosquitoes, and so become a source of malarial fever.

When constructing embankments, profiles of lath or bamboo and spun yarn should be set up at about every 50 feet; these should be of the finished section after allowing for settlement.

In low embankments, up to 5 feet in height, it will generally suffice to plough up the ground to the full width, and remove all rubbish, roots, and vegetable material, but on wet marshy soils, and in high embankments, it may be necessary to excavate the ground, and put in a solid foundation of sand or gravel. The earth should be placed on the site in successive layers 3 to 4 feet thick, and thoroughly rammed or rolled; it is important that these layers should slope inwards, and that the central portion should be filled last, as by this means the tendency to slide outwards is counteracted. In no case should the material be tipped along the centre and spread outwards; if time will not permit the thorough consolidation of successive layers, the material should be tipped along each side and filled inwards to form the centre of the bank.

Embankments should be made up to greater dimensions than the finished requirements, and should be allowed one season in which to settle before the road is laid. The amount of settlement may vary between one-twelfth and one-fifth of the height, according to the material.

A change of grade should never take place on an embankment.

4. **Sidelong ground.**—The quantities of excavation and embankment on sidelong slopes will be made to balance one another wherever possible (*see* Sec. **13**).

The principal difficulty in sidelong ground arises from the tendency of the embanked portion to slip down the hillside, and provision against this must always be made. In the case of moderate slopes the natural surface beneath the embankment must be stepped or benched, as shown on Pl. **14**, Figs. 1 and 2, and adequate slope must be given to the side of the bank. Where the inclination of the ground is considerable retaining walls are generally required, both to support the bank and to prevent slips on the hillside obstructing the excavated portion; an example of this is illustrated on Pl. **14**, Fig. 3.

These retaining walls may be built of stone, either dry or laid in mortar, brick, or concrete (*see* Sec. **49**).

CHAPTER IV.

PERMANENT MACADAM ROADS.

22. *Preliminary considerations.*

1. All roads which are deliberately constructed outside a theatre of war may be regarded as being of a permanent type, and in all cases the best modern practice will be followed, due regard being given to local conditions. Permanent roads are made to give access to standing camps, barracks, store depots, &c.

In new countries and in India, permanent road making for the development of those countries is often undertaken by the Royal Engineers.

2. **Macadam roads.**—Omitting streetworks, which include all kinds of paved surfaces and cement concrete, bituminous, or asphalt surfaces, the principal type of road in general use is that known as macadam road, either tar or water-bound.

The term macadam is now rather loosely employed to denote a surface which is produced by the consolidation of road-metal in the form of stone of varying sizes, but the original roads constructed by Macadam were formed of successive layers of small stones of 2 or 3-inch gauging, and not of greater weight than 6 ozs. Telford introduced a solid foundation of hand-packing soling, consisting of 8 or 10-inch material, over which the smaller road-metal was consolidated. The modern macadam road is a combination of these two systems, but the soling or pitching is generally considered essential when dealing with heavy traffic.

In the construction of such a road the principles of road construction, as described in Chap. III, will constantly be adhered to; the more permanent the road the more deliberately must these principles be applied.

A typical cross-section of a modern macadam road is shown on Pl. **13**, Fig. 1. The points of importance in the construction of such a road, by neglect of which failure may result, are :—

(i) Careful consolidation and drainage of subgrade or formation.
(ii) Proper laying of soling.
(iii) Selection of best available road-metal ; soft stone should be avoided.
(iv) Good consolidation and binding material; no earth or clay should be used.
(v) Attention to surface drainage.
(vi) Prevention of *spreading*.

23. *Construction.*

1. The details of gradients, widths, and lay-out of permanent roads are given in Chap. II.

2 **Drainage.**—The drainage system is described in Sec. **17.** Pls. **9** and **13** show types of side drains. In tropical countries it is important that these side drains be of sufficient size to cope with local climatic conditions.

3. **Formation or subgrade.**—The preparation and drainage of the ground on which a road is to rest is fully dealt with in Chap. III, Sec. **18.** The formation should always partake of the form of a bank which will assist drainage and **not** that of a canal which will hold water; it should generally be consolidated with the camber which will be required by the finished surface.

For a water-bound surface the camber should be from $\frac{1}{24}$ to $\frac{1}{30}$ of the width of the roadway; if the centre is given a greater elevation than this there will be a danger to traffic through skidding.

4. **Foundation.**—This is discussed in Sec. **19.** The foundations of a macadam road should be on the Telford principle, *i.e.*, a paved foundation in which large 10-inch stones are now generally used (*see* Pls. **9** and **13**). The stone must be of a durable nature and hard, but not necessarily as hard as the surfacing material; soft stone will be crushed.

The stones are carefully prepared, laid by hand, and consolidated; they are set with their greatest length across the road and their broader ends downwards, and are arranged to break joint as much as possible, all projecting points being broken off with a hammer so that a fairly even surface is obtained. The interstices are then filled with chippings to form a compact foundation, which is consolidated generally with the camber required by the finished surface of the road.

If suitable material for soling is not available, the best substitute must be used; in these circumstances unbroken stone selected from the surfacing material will be found to be the most suitable and also the most likely to be available. Other substitutes are hard-core and macadam. A hard-core foundation consists of a layer of broken brick, clinker, or other similar material; a macadam foundation is made of stone of small gauging (3-inch), and is not suitable for heavy traffic.

Useful specifications for macadam roads with hand-pitched, hard-core, and macadam foundations are given in para. 7 of this section.

5. **Surface.**—The principles dealing with the surfacing of a road are discussed in Sec. **20.**

The surface structure of a water-bound macadam road should consist of small hard insoluble stones; the properties of the various kinds of road-metal are discussed in Appendix I.

The size of metal should be limited to 2-inch gauging for hard stone, or $2\frac{1}{2}$-inch gauging for softer varieties. It should be laid on the prepared foundation in two separate layers each 4 to $4\frac{1}{2}$ inches thick; each layer should be rammed and rolled separately to a thickness of 3 inches, making 6 inches in all. The top layer should be properly consolidated to the required camber by means of a road templet (*see* para. 6). The camber is usually $\frac{1}{24}$ to $\frac{1}{30}$ of the width of the roadway. The surface should not be left to be consolidated by traffic, as it is certain to become uneven if this is done, and also horses' feet will suffer; a new road, unrolled, will never be used if it can be avoided by detours or side tracks (*see* Pl. **13**).

The sides or haunches of a road should be rolled first in order to push up the metal towards the centre and preserve the camber. The road-metal should be rolled at least five times dry, and the surface then finished off with binding material and water and again rolled 20 to 30 times. The binding material should consist of sand, gravel, or granite chips and screenings; on no account should mud or road-scrapings be used. It is spread from shovels in front of the roller, and water is sprinkled over at the same time; men should be kept sweeping the road behind the roller in order that all cavities are filled with the material, and the metal thus held together. About 15 to 20 tons of good binding is required for every 100 tons of metal.

Rollers should not exceed 10 to 12 tons in weight, otherwise they will be likely to break pipes under the roadway or crush the metal; if too wide, they cannot maintain a proper contour of cross-section. Bullock rollers are used in India and S. Africa, their weight being increased by water ballast. Those with reversible poles are the more convenient.

The spreading of the surface is prevented either by a revetment wall, as shown on Pl. **9**, by the improvised method shown on Pl. **22**, or by gutters and kerbs, as shown on Pl. **13**.

Surface water, with the aid of the camber given to the finished surface, will find its way to the edges of the road, whence it can drain direct into the side drains, as shown on Pl. **9**, or be collected in gutters and led away to a sewage system, as shown on Pl. **13**; further details of gutters and kerbs are given in Chap. IX.

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

6. **Road templet.**—It is very advisable to have a wooden templet to gauge the curvature of the roadway while it is being rolled and consolidated, and to ensure that the correct camber is given to the surface. A good form of templet is illustrated on Pl. **13**, Fig. 3, and the method of construction in Fig. 2. Such a templet covers half the breadth of the metalled portion of the road, and is used alternately on each side. It is fitted with an arm and plumb-bob as shown, and is formed of $\frac{3}{4}$-inch planking, the lower edge being cut to the required curvature.

The radius of the required curve being very large, generally over 150 feet, it cannot be drawn by means of a string and the following method should be adopted in cutting out the planking:—On some smooth surface, such as the floor of a room, make AB equal to the breadth of the roadway; bisect AB at C, and set up CD perpendicular to AB and equal to the required camber; at A set up the perpendicular AE equal to twice CD; divide AE and AC each into the same number of equal parts e_1, e_2, e_3, &c., and c_1, c_2, c_3, &c. Join e_1, e_2, e_3 to B and set up perpendiculars at the points c_1, c_2, c_3, &c. The points of intersection o, o, o, &c., are points on the required curve. Join AD, then the perpendicular distances from AD to the points on the curve measured off the edge of the plank, as shown by the dotted lines, give the required curve to which the plank should be cut.

7. **Useful specifications.**

(*a*) *Macadam road with hand-pitched foundation.* Pl. **13**, Fig. 1.—This type should, if possible, invariably be used, and is essential for heavy traffic.

The subgrade having been prepared according to local conditions:—

(i) Foundation of 10 to 12-inch soling is carefully laid by hand, and the interstices are filled with small material.

(ii) A 4-inch layer of $2\frac{1}{2}$-inch road-metal is spread over the foundation and rolled, while dry, to a thickness of 3 inches.

(iii) A $\frac{1}{2}$-inch layer of sand or gravel is rolled in.

(iv) A second 4-inch layer of 2-inch metal is spread over and rolled, while dry, to a thickness of 3 inches.

(v) A final coating of sharp sand, gravel, or granite chippings is added and rolled, with the addition of water, until a smooth surface is obtained.

No rolling or watering should be carried out in frosty weather.

On a soft or clay subsoil a layer of well-burnt clinker should be consolidated to a depth of from 3 to 6 inches before the soling is laid.

The camber should be 1 in 24 to 1 in 30.

(*b*) *Macadam road with hard-core foundation.*—This type can be used when no suitable stone is available for soling.

(i) An 18-inch layer of hard-core is consolidated to a thickness of 12 inches.

(ii) A 4-inch layer of $2\frac{1}{2}$-inch road-metal is spread over the hard-core foundation and rolled to a thickness of 3 inches.

(iii) A second 4-inch layer of 2-inch metal is spread over the first layer and rolled to a thickness of 3 inches.

(iv) A layer of sharp sand or gravel is spread over, well watered, and rolled to form the finished surface.

Hard-core should not exceed half-brick size, and may consist of rubble from hard well-burnt bricks, or well-burnt clinker free from waste metal and unscreened.

A 12-ton roller is useful for this type of work.

(*c*) *Macadam road with macadam foundation.*—This type is only suitable on a good soil and where only light traffic is anticipated. Special attention must be paid to the preparation and drainage of the subgrade.

(i) A layer of 3-inch metal is laid and rolled to a thickness of 8 inches.

(ii) A second layer of 2-inch metal is spread over the first layer and rolled to a thickness of 4 inches.

(iii) Binding material of sand or chippings is added, well watered, and rolled to form the surface.

24. *Tar macadam.*

1. Water-bound roads are not impervious, and the amount of moisture contained in them will vary according to weather conditions. In wet weather they become sodden and produce an excess of mud, especially when the softer types of stone have been utilized; in dry weather frequent watering is necessary to allay dust, and to supply the necessary moisture without which increased internal abrasion and ravelling will be set up.

Tar-bound roads are impervious. The metal is firmly held together in an elastic matrix, and abrasion is reduced to a minimum, in consequence of which an inferior quality of stone may be safely used. A porous variety, such as limestone or slag, is held to be advantageous, as it absorbs a certain amount of tar, and also wears more evenly than the harder rocks. The dust nuisance is also considerably decreased, and the weight of traffic is more evenly distributed over the foundation.

The construction of these roads is not of frequent military occurrence, but the principal methods of applying the tar will be briefly described. Details regarding this class of work will be found in the many civil text-books on road construction, to which further reference should be made.

2. The methods in common practice by which the tar is incorporated with the road-metal to form a bituminous matrix or binder can be divided into two principal classes; namely, (*a*) the preparation of a bituminous or tar concrete by a thorough mixing of the tar and the road-metal before laying, the mixture being subsequently consolidated in the usual manner, but of course without the use of water; and (*b*) the application of the hot tar or pitch to a partially consolidated and perfectly dry surface in order that all interstices shall be completely filled, commonly called *pitch grouting* or the *pouring-in-process*.

3. There is much controversy on the relative merits of the different types of road-metal; some engineers favour granite, others limestone, while the success which has attended the use of the preparation supplied in bulk by Messrs. Tarmac, Ltd., in which specially selected blast furnace slag is used, has proved that this is an excellent material.

It is generally admitted that the hardest types of basalt do not provide the best material for this class of work, and that a softer stone is preferable provided the mixing is thoroughly carried out; a rough surface and fracture are essential for the adherence of the tar, and the percentage of voids should be reduced to a minimum by careful grading of the material. The value of limestone appears to be due to the ease with which this combination is effected. In India, nodules of Kunkur form a suitable metal. In the execution of military work of this kind, where local resources have to be utilized and plant improvised, it must be borne in mind that the hardest and smoothest rocks are unsuitable, and that the preparation of the tar must be carefully carried out in order that a maximum degree of viscosity may be secured and at the same time brittleness on cooling avoided.

4. **Tar macadam.**—The tar concrete described in the preceding paragraph may be mixed by hand or by the aid of some form of mechanical mixing plant. The latter method is only economical in the case of large works, or when the plant can be installed in a central position for the supply of material over a large area, and even then it is advisable, if possible, to obtain it from firms which specialize in its production. A careful estimate of the amount of work required annually will be necessary in deciding whether the expenditure to be incurred in installing a mixing plant will be justified; as a rough guide, it may be assumed that for the treatment of an area of less than 5,000 square yards per annum hand-mixing will be the more economical method under normal conditions of supply and labour.

In preparing the mixture it is essential that the stone should be heated until thoroughly dry, and that the tar should be applied to it while still warm. The stone is usually of from 2½ to 1½-inch gauging, according to its nature; the larger material is laid first, and fine material of ¾-inch gauging is used as a binder for filling the interstices. The tar should be applied at a temperature of about 100° C., and should be of the quality described in Appendix IV; the use of crude tar is detrimental. The proportion of tar to stone will vary according to the nature and quality of the latter; it will usually be from 9 to 15 gallons to the cubic yard for the 2½-inch stone and rather more for the finer materials. Each stone should be well covered with tar, but there should be no dripping of the tar from the metal.

Hand-mixing may be carried out by heating the stone over a coal or coke fire on a wrought iron plate supported by brick piers. When sufficiently hot and thoroughly dry, a known quantity of the stone, say ½ cubic yard, is placed on mixing boards, and the requisite amount of hot tar added; the mixture is then thoroughly turned with hot shovels, as in the manufacture of cement concrete.

Care must be taken that the stone is not overheated, as this will result in deterioration of its quality owing to calcination or other causes; the maximum temperature to be reached should not exceed 112° C.

It is of equal importance that the tar should be heated to the correct temperature; 100° C. is the usual figure, and 120° C. should not be exceeded, otherwise the matrix may become too brittle on setting.

5. **Mixing plant.**—There are many varieties of mechanical mixing plants for the production of tar macadam in bulk. The essential parts of any such plant, in addition to the driving power, are (*a*) the drier, generally in the form of a revolving drum placed over a furnace, (*b*) one or more tar boilers, and (*c*) a mixer, into which the heated stone and tar are placed in the correct proportion. Pl. **15**, Fig. 1, shows a type of mixing plant.

6. **Laying tar macadam.**—Tar macadam is either laid hot and immediately it is mixed, or stored in heaps and brought to the road as required. The former method is usually adopted in the case of small works or for repair purposes.

The foundation is carefully prepared as for an ordinary water-bound macadam road. A layer of the larger gauging of tarred stone, from 2½ to 2 inches, is then spread over the foundation and rolled to a thickness of 3 inches. It is essential that a roller of medium weight be used, as one heavier than 8 tons is liable to damage the material; good results may be obtained with a 6-ton roller. The rolling should be carried out from the sides of the road towards the centre in order to preserve the camber. A layer of 1½-inch material together with ¾-inch binding material is then rolled into the first layer to a thickness of about 1½ inches; it is important that this finer material should penetrate into the interstices of the layer beneath it, and the rolling must be continued, and material added if necessary, until there is no impression at the required thickness. The surface is sealed by coating it with hot tar to prevent the percolation of water into the interstices, and sprinkled with granite or gravel chippings. As this surface is of a more slippery nature than that of water-bound macadam, a gradient of 1 in 25 should not be exceeded.

7. **Pitch grouting.**—This method of achieving a similar result to that already described is very successfully employed in many localities, and possesses the advantage that large areas may be treated without the necessity for the installation of a special mixing plant. It is important,

however, that the pitch mixture should be very carefully prepared ; a specification for the preparation of this mixture is given in Appendix IV.

The foundation of soling is prepared in the usual way, and a layer of 2½-inch metal is spread over it to a thickness of about 3½ inches ; this layer is then well rolled with a light roller, without the use of water, and is thoroughly grouted with a hot mixture of pitch and creosote oil ; the rolling is then continued until the whole layer becomes thoroughly impregnated with the mixture and completely consolidated. Before this first layer has set, another layer, 2 inches in thickness and of 1½-inch metal, is placed upon it and treated in an exactly similar manner, after which the surface is well sprinkled with granite or gravel chippings, and the roller passed over it again to complete the consolidation. Sand mixed with the chippings gives better foothold for horse traffic.

Some of the important points to be borne in mind in carrying out this class of work are :—

(i) The use of metal of too large a gauging will increase the percentage of voids, and, therefore, necessitate a larger amount of pitch.

(ii) The mixture must not be allowed to cool before application, otherwise setting is liable to commence before its penetration is complete.

(iii) The metal must be perfectly dry, otherwise the pitch mixture will not adhere to it.

(iv) The remarks with reference to the use of too hard a stone in paras. 1 and 3 are equally applicable.

(v) The mixture must be applied in sufficient quantity to ensure that the interstices are completely filled.

It is pointed out that this method is not successful in tropical countries owing to the softening of the pitch in hot weather ; natural bitumen must be used instead of pitch in such localities.

8. **Useful specification.**—The following specification is applicable to a tar macadam surface on a hand-packed foundation as prepared for a water-bound road.

(i) A layer of 2½-inch tarred stone or slag is rolled to a thickness of 3 inches.

(ii) A second layer of 1½-inch material is rolled into the first layer to a thickness of 1½ inches.

(iii) During the rolling of the second layer binding material of ½ to ¾-inch tarred stone is spread in front of the roller.

(iv) The finished surface is sealed by tar painting and sprinkling with gravel or chippings.

25. *Dust prevention.*

1. **Formation of dust.**—With the introduction of self-propelled traffic the prevention of dust became of paramount importance. Dust is one of the principal evils which road authorities have to contend with as it causes much annoyance to the public, is a source of danger to health, and increases the road maintenance bill in every community.

Production of dust and loss of material from mere *weathering* are small as compared with the grinding action of animals hoofs, vehicular traffic, brakes and skids, &c. The difference between the damage done to roads by horse-drawn and motor traffic is largely due to the fact that in the latter the propulsive power is applied through the tyres instead of by the horse, the driven wheels having a churning effect which is very destructive to the road surface, especially when a heavy axle load is supported by them. Further, the thrust of a large diameter wheel tends to displace the road-metal less than that of an equally loaded small wheel, the road being the fulcrum about which the turning moment takes place.

2. **Dust preventives.**—The remedy cannot wholly be found by the road engineer; improvement in the design of motor vehicles will greatly assist.

As far as the roads are concerned, the solution of the problem lies in the careful selection of tough and suitable material, treated with tar whenever this can be economically done, or carefully laid with a minimum of binding consisting of fine granite screenings, and finished with a tar-sprayed surface.

As it is impossible to change completely the character of existing road surfaces, their improvement by the application of some dust-reducing surface coat is generally considered necessary on main roads, and the application of refined tar in the form of tar spraying or painting is the most popular method. Crude tar will produce a sticky road, and, after rain, water splashed up will stain fabrics. Surface drainage from roads treated with crude tar is very destructive to fish, and may result in large compensation claims having to be met, if it is allowed to discharge into streams in the vicinity of fisheries. Other remedies are watering and the treatment of the surface with various oils and *dust palliatives*; the latter are very numerous, but no method has achieved the success which has attended the careful use of refined tar (*see* Sec. **26**, para. 3).

26. *Maintenance of macadam roads.*

1. Maintenance consists in the continuous preservation of a road in a good state by means of routine work carried out by a permanent staff; if this can be successfully achieved, large repairs, involving the employment of casual labour, will not be of frequent occurrence. The efficiency of a road depends on the condition of its worst section, and the engineer in charge should make himself acquainted with the whole length of a road by means of periodical inspections, in order to determine the needs in respect of large repair works and to draw up a definite programme showing priority of work. In detailing maintenance sections, the road should be carefully marked out into miles and quarter miles; this greatly facilitates locations. Statistics of the cost of all annual repairs in each section of a road should be kept for purposes of estimate and comparison, both with other roads and between different classes of material. From 60 to 75 per cent. of the funds available for upkeep should be allotted for repair works, and the remainder for maintenance. Re-metalling, including a reserve of material for the following year and the cost of laying any which has already been accumulated, will probably be the largest item.

The engineer should maintain in his office :—

(i) Plans and sections of the road surface and of all important works.
(ii) A statement, mile by mile, of the correct formation widths, average, maximum, and minimum.
(iii) Registers of all land occupied by the road, buildings, and quarries.
(iv) Road charts showing the annual progress of surfacing, mile by mile.
(v) Schedules of the rate cost of preparing materials at the quarries, and the cost of transport from them.
(vi) Annual inspection reports on the roads, their buildings, bridges, and cross-drainage works.
(vii) Annual reports of abnormal floods.

The main principles to be followed in maintaining macadam roads are :—

(i) Frequent removal of mud and dust which, if left, greatly assists deterioration by grinding action.
(ii) Prompt repairs by the renewal of lost material.
(iii) Complete renewal of the waterproof covering to the foundation before the surface has worn through.
(iv) Efficient drainage.

2. **Wear of roads.**—The wear of a road surface can be attributed to the combined action of traffic and weather. The wear on a water-bound road may be classed under three headings :—

(i) Surface wear due to traffic.
(ii) Surface wear due to weather.
(iii) Interior wear due to weather and intensified by traffic.

If the wear under (i) is small and under (ii) and (iii) large, then, if any means can be taken to eliminate weather effects, the cost of maintenance will be considerably decreased. Provided that proper drainage for the foundation is maintained, the provision of a waterproof surface will reduce the effects of weather to a minimum.

As regards traffic, heavy mechanical transport and high-speed motor vehicles cause damage to the road which can only be minimized by careful design of the vehicles : there is need for closer collaboration between the road constructor and its user in this respect. Reasonable means of reducing the damage to roads should be enforced. The life of roads may be prolonged by using wheels of large diameter, tyres of width suitable to the axle loads, rubber tyres and proper springing wherever possible, and reduction of speed to a minimum on curves.

3. **Surface maintenance.**—Work must constantly be carried out by the permanent road staff in order to maintain the surface in good condition. The principal duties of each man in charge of a section of the road will be to keep it free from loose stones and mud, to attend to the drainage and clear out gullies, and to keep footways clean and smooth.

Tar macadam roads should be sprinkled with gravel or granite chippings in frosty weather, particularly on steep hills.

Yearly tar spraying will increase the life of a water-bound road by 100 per cent., provided the foundation is good; it is generally carried out as routine work on main roads. In addition, tar spraying is an excellent dust preventive (*see* Sec. **25**, para. 2).

Cleansing.—The periodical cleansing of a road surface will effect great economy by preserving its life: the more frequently mud and dust are removed, the slower will be the disintegration of the surface. It has often been stated that good cleansing is worth a layer of metal: in carrying out cleansing work, however, the nature of the stone must not be forgotten. In very dry weather, roads made of siliceous or flinty material will tend to work loose, and a certain amount of the binding material will find its way to the surface; this should not all be removed, as it will be forced into the road again as soon as the dry weather ceases; judicious watering is necessary to keep this material down. Too much water, on the other hand, tends to assist disintegration in the case of limestone.

Removal of mud.—Sweeping and scraping may be performed either by manual labour or by mechanical means. Mud must be in a sufficiently fluid condition to be capable of easy removal, otherwise damage will be done by scrapers through the loosening of the surface metal.

Mud should be removed from the vicinity of the road whenever possible; if it is piled in heaps along the roadside there will be a danger of interference with the side drains, and also, when dry, it will considerably increase the dust nuisance.

Tar spraying.—The following are guiding principles in the use of tar for surface work:—

(i) The road should be thoroughly cleansed of dust and mud by stiff brooms.

(ii) No tar must ever be applied to a road which is not absolutely dry to a point at least ½ inch below the surface.

(iii) Great care should be exercised in the selection of the tar. The various proprietary tar compounds are generally satisfactory, but crude tar must be prepared in tar boilers before it can be used (Appendix IV).

(iv) Only that amount of tar should be applied to the surface which will cover it evenly: between ¼ and ⅛ of a gallon per square yard is the usual amount. Traffic should not be allowed on the road until the tar has thoroughly hardened; this is best arranged by treating half the width at a time. The grit which must be spread over the tar should be ½ sand and ½ coarse grit, or flint or granite chippings not exceeding $\frac{3}{16}$-inch gauging. When granite chippings are used, it is advisable to pass a roller over the surface a few hours after it has been completed.

Tar is applied to road surfaces either by *hand-painting* or *mechanical sprayers.*

Hand-painting may be carried out as follows:—The tar is delivered in casks at various points along the road, from which it is placed in a tar boiler and heated; if necessary, the required degree of refinement must be attained before the tar is used. These boilers have a 2-inch discharge pipe and plug which is opened as the boiler is drawn along: the painting gang follows with brooms and thoroughly spreads the hot tar as it falls on the road. A second gang follows and spreads the grit and sand thinly over the whole surface. In estimating labour for this work, an average daily task for 6 men using a 320-gallon boiler is 5,000 square yards. All tarring must cease if rain falls, and should not be resumed until the road is quite dry.

Mechanical sprayers are of two types, pressure machines and gravity machines. The simplest form of pressure machine is an ordinary tar boiler fitted with a hand pump having a flexible delivery pipe with a specially designed nozzle which discharges the tar in the form of a fine spray. In a larger type, power driven, the tar is kept hot by means of steam coils placed in the bottom of the tank. The pump is worked from the rear wheels of the machine, and is consequently only in action when the vehicle is moving, but can be thrown out of gear, when necessary, by means of a clutch. The spraying is done by a series of nozzles placed at the back of the machine and near the road surface. The area covered by the spray can be adjusted so that 1 gallon of tar can be used to treat from 3 to 14 square yards. The sand and grit is sprinkled as soon as the machine has passed over the road.

Gravity sprayers are of many varieties; they consist of some form of tank from which the tar flows through a sprinkler of a similar nature to that fitted to an ordinary watering-cart. A weighted cylindrical revolving brush is generally fitted behind the sprayer, and a man follows with a broom to ensure that even distribution is maintained.

All tar should be passed into the tanks and boilers through a fine mesh wire screen to intercept all solids; boilers should be replenished as the work proceeds and the tar kept boiling so that there is no delay through an empty boiler being refilled and the tar brought up to boiling point.

4. **Patching.**—The carrying out of minor repairs by patching is necessary to keep the surface in good condition, and is a method of dealing with irregular wear by means of maintenance gangs, kept on the road throughout the year, who will attend to the bad spots as they appear, thereby delaying the ultimate necessity for re-surfacing the whole road. Ruts and pot-holes will be dealt with on the lines laid down in Sec. **36**, para. 3. If tar macadam is being used, it is necessary to cut out the rut or hole square, remove all worn material, and allow it to dry thoroughly; the cavity is then brushed over with hot tar, and new material of 1¼ to ¾-inch gauging is thoroughly rammed into it; such a patch should not be finished off more than ¼ inch above the surrounding surface. Patching on a larger scale consists in applying coatings of new road-metal at intervals along the worst lengths of the road; these will usually be spread alternately on either side of the centre in order to cause as little inconvenience to traffic as possible, and also that the wheels of vehicles may assist in their consolidation, while horses' feet may travel on the old surface. These patches should not exceed 4 or 5 yards in length and 1½ to 2 yards in width. It is generally necessary to spread a quantity of small material round the edges of the patch to enable the wheels of vehicles to work gradually from the sides to the centre of the patch.

The following figures will be of use in estimating the amount of material required for patching: a cubic yard of screened metal, 1-inch gauge, spread 1 stone thick will cover about 45 square yards; 2-inch gauge about 27 square yards, and 2½-inch gauge 24 square yards. If the metal is to be spread to a thickness of 2 or 3 stones the area covered will be less than would be assumed from these figures on account of the compactness caused by consolidation and the lesser percentage of voids.

If mechanical rollers are used for consolidating patchwork, it must be borne in mind that, although the best surface will be obtained by their use, the amount of work required must be of sufficient quantity to make it economical to bring them to the site. The quantity of material in patches which can be consolidated by a heavy roller will vary between 20 and 30 tons a day, according to the volume of traffic using the road and causing stoppages.

5. **Renewal of surface.**—If repairs by patching have not been carried out or cannot be effectively resorted to, it will be necessary to renew the whole surface of the road by consolidating a new surface layer of macadam in a similar manner to that employed in constructing a new road. It is usually necessary to scarify the old surface, unless the wear has been very even and uniform and a tough stone has been used; this may be done by means of picks, but is usually carried out mechanically by the scarifying attachment fitted to steam rollers.

The whole surface is scarified, and, if necessary, old metal is removed and screened to eliminate the worn or rounded stones and grit; the contour of the road is then prepared to receive the new metal, and this is consolidated in the usual way.

Road-metal for maintenance or the renewal of a surface is stacked at recessed intervals along the edge of the road; the stacks should be so arranged that their cross-section is constant, and corresponds with a gauge containing an even number of square feet; this not only assists measurement, but prevents fraud. In India, Kunkur is so left for one year, so that all the earthy matter may be washed out by rain, and that it may harden.

6. **Rolling.**—This is an operation which requires greater care and skill than was formerly thought necessary: the passing of a heavy roller to and fro over the loose metal in a haphazard manner will produce an inferior surface to that resulting from methodical consolidation. Rolling should never be carried out to the extent of crushing the material, only so far as will sort and fix it.

Modern experience is proving that the older rollers were too heavy, and that lighter rollers and slower consolidation give greater ultimate solidity and less waviness in the surface. The most satisfactory method of all is to start with a light roller, 6 to 8 tons, and finish with a heavy one, 10 to 12 tons, but this is not always convenient; ballasted rollers have been introduced for this purpose. The action of a heavy roller on the metal in a loose state tends to produce crushing and attrition rather than consolidation, and also a waved surface due to the material being pushed up in front of the roller and displaced before the latter passes over it. A surface should be thoroughly consolidated in a dry state before any water is added. When a *mosaic* appearance has been obtained the water may be sprayed over; not more than 4 gallons per square yard of surface should ever be used, and under favourable conditions this amount should be reduced to 2 gallons. The nature and quantity of binding material to be used will depend on the type of road-metal being used (*see* Secs. **23** and **24**), but it should be borne in mind that no material of an earthy or vegetable nature should ever be employed in this capacity.

In all rolling operations the roller must be continued working backwards and forwards gradually from the sides towards the centre of the road, and the wet binding material should be continually swept over the surface in front of the roller in order that all interstices may be filled. When the whole surface is thoroughly consolidated and no further movement under the roller can be detected, all surplus water and binding material must be swept off.

CHAPTER V.

ROADS, &c., DURING NORMAL OPERATIONS IN A SMALL WAR.

27. *Introductory.*

In this chapter will be discussed various types of roads, &c., which are typical of what would be required during the normal operations of a small force acting in an uncivilized or only partly civilized country, *e.g.*, on the N.W. frontier of India, in Africa, Persia, and elsewhere.

Road making in mountainous country, however, presents special difficulties, and will, therefore, be dealt with separately in Chap. VII.

The types to be discussed in this chapter are :—

(i) Macadam roads. Sec. **28.**
(ii) Corduroy and plank roads. Sec. **29.**
(iii) Roads over marshy ground. Sec. **30.**
(iv) Desert roads. Sec. **31.**
(v) Earthen roads. Sec. **32.**
(vi) Cross-country tracks. Sec. **33.**

28. *Macadam roads.*

1. **Construction.**—The methods of constructing a macadam road are described in detail in Chap. IV. Briefly the operations are as follows :—

(i) Peg out centre-line.
(ii) Mark out side drains.
(iii) Insert subsoil drains when these are necessary for the drainage of the formation (*see* Pl. **22**).
(iv) Throw earth excavated from side drains into the centre to form the bank and camber, getting additional earth for this from borrow-pits if necessary ; this earth must be thoroughly rammed.
(v) Lay the foundation or soling by hand ; the stones must be carefully packed and laid with the longest sides across the road and the broader ends downwards. An outer wall of stones should be built up in a small trench at the edges of the road to prevent the road spreading, as shown on Pl. **9.**
(vi) Lay broken stone or macadam of 2-inch to 2½-inch gauging, according to the variety of stone being used, in a 4½-inch layer, and roll this well in. Lay a second similar layer of slightly smaller gauging, and roll this in.

(vii) Finish off the surface by rolling in stone chippings or gravel and last of all a little sand.

(viii) Put in pickets to keep the traffic on the metalled surface; they should have a slight outward slope (*see* Pl. **9**).

On a single-way road the pickets must be spaced so that vehicles may overtake and pass slowly-moving traffic. With a double-way road on a hillside, pickets should be driven in every 4 to 6 feet close up to the haunches of the road, on the outer edge, and a rough plank revetment built in behind them to prevent the road spreading (*see* Pl. **9**, Fig. 2).

Pl. **22** shows a cross-section of a road constructed as above in which drainage precautions are clearly shown. The strutting of the side pickets is a common practice resorted to in order to prevent spreading, and also to minimize the tendency of the drain to fall in.

Single-way traffic requires a minimum width of 9 feet; double-way traffic requires a minimum width of 18 feet, but 24 feet is preferable. (*See* Sec. **10.**)

2. **Improving existing roads.**—Many existing roads follow routes which are of military importance, and will have to be adapted to meet requirements. They may, or may not, have metalled surfaces, but it will generally be found that considerable work is required to render them fit to cope with the increase of traffic.

If unmetalled, the procedure will be similar to that already described, and the formation will be consolidated after efficient drainage has been provided for.

In improving a metalled road in poor condition, the following is the order of urgency of work :—

(i) **Establish longitudinal side drains,** and cut wide gaps through the banks of earth, mud, and rubbish which it is safe to assume will be found on the berm along both sides of the road. This will enable the road to be drained. In very bad places it may be necessary to add subsoil drainage. (*See* Sec. **18.**)

(ii) Sweep mud and water off the road into the side drains, using brooms; scrapers and shovels should not be used to remove mud and water.

(iii) Throw all solid mud, debris, or spoil clear of the drains on the far side.

(iv) Repair the worst ruts, by cutting them out square and filling in with metal well rammed.

(v) If sufficient road-metal is available, restore shape and camber to the surface, treating half the width of the road at a time, length by length. First scarify the old surface with picks, then spread macadam to the required thickness, using a templet, and roll well in. Unless the old surface is well picked over, the new macadam will not bind with the old metal.

(vi) Earth berms at the sides should not be interfered with until they can be replaced by stone, as their removal will leave no support to the metalled width against spreading.

3. **Treatment of sunken roads.**—Sunken roads are generally developments of old tracks cut through undulating country. They are often

In all rolling operations the roller must be continued working backwards and forwards gradually from the sides towards the centre of the road, and the wet binding material should be continually swept over the surface in front of the roller in order that all interstices may be filled. When the whole surface is thoroughly consolidated and no further movement under the roller can be detected, all surplus water and binding material must be swept off.

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(v) Lay the foundation or soling by hand ; the stones must be carefully packed and laid with the longest sides across the road and the broader ends downwards. An outer wall of stones should be built up in a small trench at the edges of the road to prevent the road spreading, as shown on Pl. **9.**
(vi) Lay broken stone or macadam of 2-inch to 2½-inch gauging, according to the variety of stone being used, in a 4½-inch layer, and roll this well in. Lay a second similar layer of slightly smaller gauging, and roll this in.

(vii) Finish off the surface by rolling in stone chippings or gravel and last of all a little sand.

(viii) Put in pickets to keep the traffic on the metalled surface; they should have a slight outward slope (*see* Pl. **9**).

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Pl. **22** shows a cross-section of a road constructed as above in which drainage precautions are clearly shown. The strutting of the side pickets is a common practice resorted to in order to prevent spreading, and also to minimize the tendency of the drain to fall in.

Single-way traffic requires a minimum width of 9 feet; double-way traffic requires a minimum width of 18 feet, but 24 feet is preferable. (*See* Sec. **10**.)

2. **Improving existing roads**.—Many existing roads follow routes which are of military importance, and will have to be adapted to meet requirements. They may, or may not, have metalled surfaces, but it will generally be found that considerable work is required to render them fit to cope with the increase of traffic.

If unmetalled, the procedure will be similar to that already described, and the formation will be consolidated after efficient drainage has been provided for.

In improving a metalled road in poor condition, the following is the order of urgency of work :—

(i) **Establish longitudinal side drains**, and cut wide gaps through the banks of earth, mud, and rubbish which it is safe to assume will be found on the berm along both sides of the road. This will enable the road to be drained. In very bad places it may be necessary to add subsoil drainage. (*See* Sec. **18**.)

(ii) Sweep mud and water off the road into the side drains, using brooms; scrapers and shovels should not be used to remove mud and water.

(iii) Throw all solid mud, debris, or spoil clear of the drains on the far side.

(iv) Repair the worst ruts, by cutting them out square and filling in with metal well rammed.

(v) If sufficient road-metal is available, restore shape and camber to the surface, treating half the width of the road at a time, length by length. First scarify the old surface with picks, then spread macadam to the required thickness, using a templet, and roll well in. Unless the old surface is well picked over, the new macadam will not bind with the old metal.

(vi) Earth berms at the sides should not be interfered with until they can be replaced by stone, as their removal will leave no support to the metalled width against spreading.

3. **Treatment of sunken roads**.—Sunken roads are generally developments of old tracks cut through undulating country. They are often

entirely devoid of drainage, consequently intensive traffic quickly renders them impassable (*see* Pl. **16**, Fig. 1).

If the side banks are not too high, the method illustrated on Pl. **16**, Fig. 2, may be adopted to improve the formation. Side drains are cut in the banks at a suitable distance from the edge of the road, and the surface is connected to these by cross-drains cut through the banks at intervals.

If the banks are too steep for this treatment, the drainage may be effected by cutting away at the sides and laying gutters to carry off the surface water, until it can be got clear of the road on lower ground (*see* Pl. **16**, Fig. 3).

4. **Repair and maintenance.**—This will follow generally the procedure outlined in Chap. IV, Sec. **26**, for a permanent macadam road.

29. *Corduroy and plank roads.*

1. The use of timber as a road surface will be resorted to as a more or less temporary measure where the traffic is too heavy for the continued use of cross-country tracks and the ground too soft to maintain them. Good plank roads are extremely useful, and will carry all kinds of traffic for a considerable time, but should be replaced by metalled roads as early as possible, as they are very vulnerable to shell fire.

The conditions governing the location of plank roads are similar to those under which cross-country tracks are laid out; more often than not the origin of a plank road is a cross-country track which has been found insufficient to cope with the traffic during long spells of wet weather. Plank roads are often used as avoiding roads and for the approaches to rail-heads, dumps, or engineer parks (Sec. **34**). In tropical countries with dense forests corduroy roads are invaluable, and the timber can be obtained on the site.

The road to be provided may be a single-way road, a single-way road which may be doubled if necessity arises, or a double-way road.

The traffic in the early stages of the operation may be horse transport only, but it must not be forgotten that lorries and heavy artillery will often come on these roads in the early stages of an advance.

2. **Material.**—For convenience of handling, corduroy timber and road slabs are cut into lengths of about 10 feet, so that the overall width of single and double-way roads are 10 and 20 feet respectively, giving a roadway of roughly 9 and 19 feet. For further details *see* Appendix VIII.

3. **Construction.**—The principles of road construction, as outlined in Chap. III, apply equally to corduroy and plank roads as to other roads. These principles are dealt with as follows:—

Drainage.—Side drainage must be established by means of two longitudinal side drains (*see* Pl. **17**); these drains must be deep enough to drain the formation.

Formation.—This must be of the nature of a bank to raise the roadway above the general level of the ground, and it can usually be formed of the earth excavated from the side drains (*see* Pl. **17**). For a double-way road the surface of the formation must be given more than the camber required by the finished surface to allow for sinking.

Foundations.—These must be made to act as a raft in spreading the weight of traffic. The road surface is supported by longitudinal runners or stringers, which in turn are supported by transverse bearers (*see* Pl. **17**).

Surface.—The road surface consists of corduroy timber, slabs, or planks held in position by ribands. Single-way roads require no camber; for double-way roads the camber, given to the surface to assist drainage, must be more than that eventually required to allow for sinking.

4. **Procedure in construction.**—The following is the process of construction for a double-way corduroy or plank road, of which cross-sections are shown on Pl. **17**.

(i) Peg out centre-line.
(ii) Mark out side drains.
(iii) Excavate and throw earth into the centre of roadway; ram this, giving an initial camber of 6 inches at the centre-line to allow for sinking. The side drains must be deep enough to drain the earth formation.
(iv) Bed the transverse bearers at 3 feet centres into and level with the surface of the formation.
(v) Lay stringers or runners, as shown on Pl. **17**; dog-spike the two centre stringers together, ram earth between the stringers.
(vi) Lay the slabs or corduroy close; if the latter is of split timbers, the flat side must bear on the stringers. Auger and spike to all the stringers.
(vii) Lay the ribands with a space of 12 inches between each to allow surface water to run off. Ribands should be spiked to the road and to stout pickets driven at 3 feet intervals along the edges.
(viii) Fill in surface interstices with sand, gravel, or earth.

The following are additional points of importance in connection with timber roads:—

(i) In swampy ground a close layer of fascines should be placed under the transverse sleepers to form a more solid formation.
(ii) In laying a single-way road, passing places 10 feet wide must be provided every 200 yards. At all places where lorries, &c., have to unload, turning places must be provided.
(iii) Holes for spikes must be bored otherwise the wood will split. 6-inch spikes should be used whenever available, as wire nails are not of sufficient strength and are found to bend when driven through hard wood. Great care should be taken that no projecting nails, which might injure horses' feet, are left.
(iv) Earth berms must be provided on each side of the roadway; they preserve the side drains, and should be at least 4 feet in width.
(v) The initial camber of the formation, 6 inches in a double-way road, will, on consolidation, produce a camber of about 3 inches, which is a good figure. An exaggerated camber is dangerous to traffic, and produces skidding in wet weather.
(vi) The necessity for revetment of the side drains must not be overlooked; this will be necessary in soft ground, and may be satisfactorily carried out by pickets and brushwood, planking, or expanded metal.
(vii) In corduroy roads where the timber is of irregular dimensions, the surface may be improved by the use of an adze.

(viii) Sand or gravel is a necessity, and must always be at hand for throwing on plank roads in greasy weather.

(ix) Skilled labour is required for laying the road, and unskilled labour for the necessary excavation and carrying.

30. *Roads over marshy ground.*

1. **Construction.**—Marsh land should generally be avoided. If the local conditions and the military situation render it necessary for a road to be constructed over marshy ground, the site must first be treated so as to provide a firm foundation, otherwise the road will certainly sink after it has been made. A very careful system of drainage, which will remain clear and unobstructed, is essential; side drains require to be wider and deeper than under ordinary conditions; when, owing to the water level, they cannot be made deeper, they should be made correspondingly wider.

On very soft spongy ground tree trunks, logs, reeds, sapling mats, fascines, coarse grass, millet stalks, or brushwood, in bundles 9 to 12 inches in diameter and about 18 feet in length, are laid alternately, transversely and longitudinally, and pegged down; the thickness of such a grillage should be at least 18 inches, and the top layer should be across the direction of the traffic; road-metal and gravel is then spread over the top of this to the required thickness. A disadvantage of this vegetable foundation is that it quickly decays if alternately wet and dry. If there is much traffic, a reserve of material should be collected and stacked to make good hollows and drainage.

A small stream in marshy ground is very troublesome to deal with; each case should be treated on its merits, but, in general, it is advisable to canalize and train it to a definite line by means of fascines, &c., cut from the long grass and reeds which are usually abundant in such localities.

2. The construction of durable roads across low-lying lands, such as salt marshes or meadows situated on tidal estuaries, is rendered difficult chiefly by the fact that the road must possess the rather opposing characteristics of lightness and strength; the former in order that it may not sink into the soft ground on which it is laid, and the latter in order that it may meet the traffic requirements, and also resist the wash of the waves that may occasionally flood it during stormy weather.

A method of construction is as follows. Large tree trunks with two opposite sides flattened are laid lengthwise, one being placed in the centre and one on each side of the road, the latter being laid approximately under where the wheels will pass. The space between these stringers is filled with well-rammed soling and shingle, and poles about 6 inches in least diameter are laid across them, as in corduroy roads. At each side, over the ends of the poles, 2-inch × 6-inch kerb planks are placed on edge, and securely fastened to piles driven 6 feet into the ground at suitable intervals, and projecting 4 feet above the road surface. 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 is formed a compact earthen bank about 2 feet wide. The space between the kerb planks is then filled with stones to the required level, and shells, gravel, and shingle are spread and consolidated to form the surface.

This form of construction gives an elevation above the tides, except during severe storms, and the road, if carefully constructed, will withstand storm waves for considerable periods.

31. *Desert roads.*

1. When operations are taking place in a desert country, the problem of providing for the needs of traffic over a surface of loose sand presents special difficulties; it will be found that the usual methods adopted will prove of no avail, as, owing to the foundation not remaining rigid on the sand beneath, it is impossible to produce a solid roadway.

The intensity of pressure due to the load must be reduced to a minimum, and, to achieve this, the effect of the traffic must be spread over as large an area as is possible, in order that the roadway may not sink into the sand under traffic and become impassable.

Various methods for the passage of light traffic over desert sands are resorted to with varying success, chief among which are the use of wire netting, tibben, tina (a mixture of sand and clay), reeds, and brushwood.

2. **Wire netting** has been found very satisfactory with judicious maintenance; a single thickness of this will carry light traffic and motor ambulances for a considerable period without renewal. The wire netting used is the ordinary *chicken* or *rabbit* wire, issued in rolls 3 feet in width; the mesh should not be greater than 1 inch in diameter.

Four widths of this are usually laid for a single track, giving a 12-foot roadway; the rolls are laced together with plain wire as they are laid.

Wooden anchoring pickets are attached with plain wire to the outer widths of the netting, and are then driven at the bottom of holes about 2 feet 6 inches deep dug along the sides of the track, at about 6 feet intervals, as shown on Pl. **18**; the anchorages are then windlassed up and buried to minimize the danger of tripping.

Traffic must never be allowed to cross such a track at right angles; where junctions or crossings occur wire netting must not be used.

Wire netting laid on sand in this manner is also used as a foundation for light metalled roads, but it cannot be employed where the sand is moist, as this condition produces rapid corrosion of the wire.

3. **Tibben** is chopped straw; 6 inches of this, well watered and rammed, will carry horse transport, and will also serve as a foundation for light metalling if a roller weighing not more than 3 tons is used to consolidate it. This method has been used with success in Egypt. In general, a combination of wire netting, tibben, tina, and light road-metal to suit local conditions must be resorted to for the passage of the lighter classes of transport over desert sands.

32. *Earthen roads.*

1. By earthen or natural soil roads is meant those formed entirely of clay, sand, and gravel. Under favourable local conditions their formation can be rapidly effected with a minimum of material and skilled labour, and in many tropical countries this type of road forms the sole means of communication. In India they are called *Kutcha* roads, and in many districts, apart from the main trunk routes, these earthen surfaces are relied on to carry the native transport.

In tropical Africa, where there is very little wheeled traffic, the majority of the roads are formed of earth; their surfaces bake very hard and become well consolidated from the thousands of natives passing over them barefoot.

Pl. **19** shows typical cross-sections of an earthen road; the principles of road construction are applicable to this type as to all other roads, especially as regards drainage, bank, and surface (*see* Chap. III).

The procedure in construction is as follows :—

(i) Remove all mud, and perishable and loose material.
(ii) Provide ample drainage.
(iii) Form and consolidate a bank, and keep the surface exposed to wind and sun.
(iv) Cover with a layer of 3 to 5 inches of coarse sand, gravel, or broken burnt clay, and consolidate well.

The surface should be given a good camber, 1 in 24 to 30 being the usual figure; on the slope of a hill this cross-section should be maintained, for experience has shown that, if a uniform slope towards the inner edge be adopted, there is unnecessary wear of the inner side of the road.

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

Gravelly soils on either a sandy or clay foundation make good roads, provided the foundation is banked and well rolled and sufficient camber is allowed. On a clay foundation a seal or layer of suitable material is necessary to prevent the clay working up through the surface. Each layer should be uniform, and not exceed 3 or 4 inches in thickness; the layers should be spread carefully and consolidated separately, otherwise a compact surface overlaying loose layers will result. Water is essential for the rolling and ramming of the surface; wooden rammers should be used.

2. In tropical countries the principal trouble with earthen roads used by mechanical transport is the formation of dust, sometimes 6 inches or more in depth, which impedes traffic and hides pot-holes; as a rule, the laying of this dust will be impracticable owing to shortage of water. An earthen road cannot be remade or repaired in the dry season. The dust should, therefore, be removed well clear of the road by scrapers; this will result in a rough surface, but pot-holes will be visible, and the dust less objectionable.

It is necessary to wait for the rainy season before any effectual improvement can be made. 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 scraper or drag drawn by a team of horses or mules. 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 dries quicker than if left coated with mud and full of ruts. Ruts should never be filled with sods, turf, or broken stone.

33. *Cross-country tracks.*

1. Cross-country tracks are invaluable for the relief of roads in dry weather, by diverting therefrom horse transport and troops; these tracks

must, however, be closed in wet weather, and in this lies their great disadvantage; but with careful traffic control and restriction to pack transport when necessary, they may even then be maintained for limited periods during times of great concentration preparatory to an attack or during an advance. They are laid out for the use of artillery limbers serving field batteries, the conveyance of rations and stores to the troops, as short cuts in and behind battle zone areas, and to avoid villages and other shelled areas. *See* Sec. **10.**

When troops are concentrated with large quantities of artillery supporting them, each infantry brigade should, if possible, be provided with its own up and down tracks with branches to serve battery positions, and these should be pushed forward simultaneously whenever an advance takes place. It is inadvisable to allow tracks to pass too close to battery positions, and concealment from observation should be aimed at, although it will seldom be possible to deceive aerial observers.

2. **Procedure of work.**—Having decided on the route of a track, the necessary work should be carried out as follows :—

(i) Mark out the route throughout its length with posts, which should be placed at intervals of 10 to 20 yards along one or both sides of the track. These posts should be painted white, or have a continuous wire stretched between them with pieces of white tape knotted to it; they should be closer at corners and difficult places. Tracks (double) should, as a minimum, be 18 feet wide for horsed transport, and 8 to 10 feet for pack animals.

(ii) Clear and roughly level the track throughout its length. All mud should be removed, and the softer parts of the ground dealt with. Fascines are most suitable for this purpose; they should be well wired and picketed to solid ground, and covered with 6 inches of earth or gravel. Corduroy road-mats (Pl. **49** and Appendix VIII) are also very useful for this work, as also for the junctions with main roads and the approaches to camps, horse lines, or water-points, such places being always wet. Shell-holes must be filled in and well rammed, but it is most important that water and soft mud should be removed from them before they are dealt with; brick rubble is useful for filling shell-holes.

Surface drainage must be provided, by means of a ditch on each side of the track; these ditches can be made to discharge into depressions or large shell-holes.

(iii) Fix notice boards where required (*see* para. 4).

3. **Crossings.**—*Trenches* should be filled in and rammed rather than crossed by bridges; the filling should be covered by a short length of corduroy road, and care must be taken that the trench drainage is not interfered with.

Streams and ditches must be crossed either by light timber bridges, or by culverts formed of timber box-drains, corrugated iron tubing, or reinforced concrete pipes. A culvert is preferable where the banks are not too high, as it enables a greater width of crossing to be more rapidly formed. Double crossings to take up and down traffic are desirable over trenches and streams, as this avoids congestion and halts at these points.

4. **Notice boards.**—All tracks must be very carefully indicated by notice boards at all crossings, road junctions, and other important points. Map references should be freely given. Arrangements must be made for the marking of tracks by night; this can be done by the use of lamps placed where they are hidden from the enemy, a useful method being to place the lamp in an empty biscuit tin, one side of which has been replaced by oiled linen on which the necessary directions are painted in black lettering. Luminous paint is useless for the marking of tracks, as it is invisible except at close quarters.

CHAPTER VI.

ROADS, &c., FOR THE OPERATIONS OF A LARGE FORCE DURING A PERIOD OF STATIONARY WARFARE.

34. *Traffic requirements.*

1. The strategical value of good roads during operations of this character is immense. The dependence of an army in the field upon the expeditious and regular delivery of supplies and ammunition to the fighting troops and the importance of lateral communication for mutual support are obvious.

Roads constructed in an area behind a large army have to meet the most exacting demands of traffic possible. The advent of all types of mechanical transport, with the resulting increase in the weight of vehicles and the loads which they carry at considerable speed, has rendered the provision of good roads of paramount importance in a prolonged campaign.

In order that supplies and ammunition may be rapidly distributed to all parts of an army which may cover a front of many miles, it will be found necessary to employ large numbers of men on the construction of new roads and the maintenance of existing ones, and also to accumulate quantities of road material at convenient depôts through the area. The absence of convenient railways will make it essential to lay down new roads, in order that troops may be quickly moved from one point to another, and that the evacuation of casualties may proceed smoothly at all times.

Roads in the concentration area differ from forward roads in that the latter will be constructed usually with the object of enabling certain fighting troops to carry out a definite operation, while the problem of the former will deal, from the point of view of a large army in the field, with the means of facilitating mutual support between different points and increasing the general welfare of the whole force.

It is obvious that the work required in the provision of such communications will approach more nearly to the procedure adopted in peace-time than is the case with forward roads. The labour employed will be more skilled, and the hours of work more regular, but all the appliances used in civil practice will not be available. There will be less chance of enemy interference except where he is in possession of long-range artillery, the same difficulties in getting material to the site will not be met with, and the use of mechanical rollers can proceed without interruption whenever such are available. More consideration will be given to the location, and surveys made whenever the country is at all difficult. Bridges will be strengthened, if necessary, to meet the extra loads which will be brought over them, and repairs to bridges damaged by enemy action will often be necessary; bridging problems are discussed shortly in Sec. **46**.

In short, the building of such roads will be carried out on the same principles as in peace-time with certain essential differences, namely, the class of labour employed, the time allowed for the work will be much more limited, the traffic will come on the road as soon as it is completed, and the supply of material will not be regular. In most cases a macadam or similar type of road will be used either with or without a tarred surface, but timber slabbing may be found useful for short lengths, as where a road is constructed to avoid a village either to relieve congestion or to prevent the necessity of using a cross-roads which the enemy has successfully registered with long-range artillery.

2. **Requirements for operations.**—Although in normal times the existing roads may be adequate for the needs of the troops, a considerable amount of provision is necessary for offensive operations on a large scale with respect to :—

(i) Roads for the extra traffic entailed by the concentration of troops and a subsequent advance. Sec. **35**.
(ii) Forward roads, &c., during operations of this character. Sec. **36**.

35. *Roads for the extra traffic entailed by the concentration of troops and a subsequent advance.*

1. The deliberate work which will be undertaken for the concentration and advance will include such items as :—

(i) Improvements to existing roads.
(ii) New roads.
(iii) New approach roads to additional rail-heads, or improvements to those existing.
(iv) Bye-pass roads to extra refilling points, water-points, dumps, &c.
(v) Entrances and exits to new camps, casualty clearing stations, rail-head rest camps, &c.
(vi) Maintenance dumps of material for road repairs.

Roads or railways.—Where there is a choice between the provision of a road or a railway to meet the traffic needs, it may be noted that in areas which can be reached by long-range artillery, railways are more liable to total interruption from damage by shelling than roads, and may, therefore, be considered as subsidiary.

In areas where extensive damage is less probable, new light or standard gauge railways can often be constructed in less time and with less labour than new roads, or an existing single line can be doubled quicker than a road can be widened.

Main roads.—The ideal of one good road of advance per division is seldom obtainable. With good traffic control a first-class road for three lines of traffic will take an enormous number of vehicles, and it is important to give priority to the upkeep of all main roads. It has been found by experience that for intensive traffic on double-way roads the metalled surface should not be less than 24 feet in width, otherwise the rate of traffic progress will be slow. Where a main road is used by two formations, it is usually advisable that only one should undertake the traffic control, although the maintenance may be divided according to formation areas.

Switch roads.—In order to avoid heavily shelled cross-roads or villages, switch roads often have to be laid down; they are preferably constructed of macadam, which is less vulnerable than timber slabbing. If the latter is used the roads must always be double traffic roads, although two single traffic roads, widely separated, are sometimes more convenient and less liable to interruption.

Approach and bye-pass roads.—The heavy traffic during concentrations at rail-heads, refilling points, dumps, and water-points renders it necessary to pay particular attention to approach and bye-pass roads. Where there is heavy lorry traffic metalled surfaces are preferable, but, if they cannot be provided, sleepers should be used; *beech slabbing*, unless of extra thickness and very carefully laid, is not strong enough. It is important that levels should be taken and a drainage scheme worked out before the sleepers are laid, as this will save much maintenance work later.

2. **Construction.**—For the very heavy traffic to be accommodated a metalled surface will generally be provided. The methods of construction of a macadam road are dealt with in Sec. **28**, and in Chap. IV. Beech slabbing as a surface for a road has sometimes to be resorted to, but it is better policy to reserve such material for forward road-work. The method of construction of a corduroy or plank road is given in Sec. **29** (*see* also Appendix VIII).

3. **Widening pavé roads.**—In some districts the central portion of country roads is paved with stone setts, laid in sand, while the borders are left unpaved. With intensive traffic these borders quickly become worn out, and often disappear into the side drains. It must be remembered that a pavé road is an arch and requires abutments (*see* Chap. IX); when these abutments disappear there is a tendency for the pavé to spread. It is, therefore, desirable that these borders should be macadamised in all cases where heavy traffic is anticipated.

The work required to effect this improvement is shown on Pl. **16**, Fig. 4. The earth sides must be excavated to a depth sufficient to admit of laying the soling and macadam surface, and to preserve the camber of the central portion, so that drainage into the side drains is not obstructed. The whole road may be supported by treating the side drains as shown.

4. **Converting corduroy roads to metalled.**—In nearly every case it is necessary to take up the old corduroy. The only exception is when the timber has sunk into soft ground, and it is possible to lay a full thickness of soling and macadam on the top. The old corduroy in this case improves the foundation of the road, but the value of timber makes it usually an urgent necessity to recover all that is serviceable.

36. *Forward roads, &c., during operations.*

1. Forward roads in warfare with a highly organized enemy include existing roads which generally require considerable repair (para. 3), and those roads or tracks hastily constructed by fighting troops in contact with the enemy. The men employed may be subject to machine-gun and rifle fire, and an enemy who is well provided with artillery will endeavour to impede the work as much as he can, should he discover its existence.

The chief objects with which they will be undertaken are :—

(i) To ensure that supplies and transport may be kept in touch with the infantry at all stages of the battle.
(ii) To effect rapid concentrations at desired points.
(iii) To facilitate the easy movement of artillery.
(iv) To furnish approaches to such temporary road bridges as have been hastily built at points not served by existing roads.

2. **Construction.**—Forward roads may vary in character from a mere cross-country track (*see* Sec. **33**) to an existing macadam roadway (*see* Sec. **28**), but in most cases something in the nature of a compromise between the two will be found to meet the requirements of the situation. The use of heavy timber planking, known as *slabbing*, to form a corduroy or plank road (*see* Sec. **29**), has been found most satisfactory, especially in soft or heavily shelled country. Time, however, is often the decisive factor in the construction of such a road, and it will be left to the officer on the site to decide in what way he can best utilize his men and available material, in order to meet the tactical requirements of the case. It will usually be advisable to first provide as good a surface as possible over the whole length required, in a minimum of time, rather than to construct a short length of more perfect road.

The traffic which will at first pass over such roads will not generally include the heaviest types of vehicles, but, on the other hand, the possibility of the route being required to accommodate all kinds of traffic should not be overlooked when the location is under consideration.

3. **Repairs to existing roads.**—The repair of forward roads during operations must be carried out rapidly, in order that communication may be interrupted as little as possible. Damage due to artillery fire in the form of shell-holes or mine craters must be made good, and repair parties should be placed on all important roads in the area of operations.

The methods employed to improve an existing road in poor condition are given in Sec. **28**, para. 2.

Ruts, shell-holes, and craters will be dealt with as follows :—

Ruts.—These should first be cut out square ; if the foundation soling has been destroyed, it must be replaced, and the macadam then laid and rammed over it ; in clay country, attention should be paid to the sub-grade before the new soling is laid.

Shell-holes.—These will vary in depth considerably. A small shell-hole may be treated in a similar manner to a rut, after its sides and bottom have been cut square and any mud or water removed from it.

There are several methods of dealing with large shell-holes, but in all cases it is essential that they should be squared out and cleared of mud and lines of traffic will take an enormous number of vehicles, and it is important to give priority to the upkeep of all main roads. It has been found by experience that for intensive traffic on double-way roads the metalled surface should not be less than 24 feet in width, otherwise the rate of traffic progress will be slow. Where a main road is used by two formations, it is usually advisable that only one should undertake the traffic control, although the maintenance may be divided according to formation areas.

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The work required to effect this improvement is shown on Pl. **16**, Fig. 4. The earth sides must be excavated to a depth sufficient to admit of laying the soling and macadam surface, and to preserve the camber of the central portion, so that drainage into the side drains is not obstructed. The whole road may be supported by treating the side drains as shown.

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The traffic which will at first pass over such roads will not generally include the heaviest types of vehicles, but, on the other hand, the possibility of the route being required to accommodate all kinds of traffic should not be overlooked when the location is under consideration.

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Shell-holes.—These will vary in depth considerably. A small shell-hole may be treated in a similar manner to a rut, after its sides and bottom have been cut square and any mud or water removed from it.

There are several methods of dealing with large shell-holes, but in all cases it is essential that they should be squared out and cleared of mud and water. Useful expedients for filling them are sandbags and wire netting, or expanded metal in alternate layers, fascines, or small cribs of pit-props filled with gravel or well rammed earth. The soling and metal are laid on this filling in the usual way. Pl. **20** shows different methods of dealing with shell-holes.

Craters.—Large mine craters are generally blown of such a size as to remove the whole surface of the road, and may be as much as 100 feet in width and 50 feet in depth. When these occur a diversion of corduroy or plank roadway must be immediately constructed to restore communications. Such diversions are generally made round each side of the crater for up and down traffic; they should be clear of the loose material thrown up by the explosion which is required for filling purposes.

For filling craters large parties of men are required with wheelbarrows, picks, and shovels, and the following is the best procedure:—

(i) Remove all sludge and water.
(ii) Fill up to within about 2 feet of the road surface with layers consisting of alternate courses of sandbags filled with dry earth and properly laid, and of rammed dry earth.
(iii) One layer of fascines, stretchers breaking joint.
(iv) Ram in dry earth to fill spaces.
(v) One layer of fascines, headers breaking joint.
(vi) A few plank stretchers along the line of traffic.
(vii) Dry earth rammed to make a flat surface.
(viii) A corduroy roadway.
(ix) Road-metal to finish off the surface.

4. **Screening.**—Where the enemy can exercise direct observation, it will usually be necessary to work by night; careful supervision of labour is then required. Should secrecy be required, steps must be taken to conceal each night's work at the approach of daybreak. This can be effected by screening, wire netting and tree branches, painted canvas, or other means of camouflage which may suggest themselves on the site, and is referred to in Sec. **38**.

5. **Labour.**—Skilled labour on forward roads should be concentrated at such points as the crossings of streams and trenches, on the preparation and fixing of notice boards, and the withdrawal of enemy mines and traps. It will always be required, however, for the laying of corduroy and plank roads and fascines after the formation has been prepared.

Unskilled labour may be used on excavation, the filling of shell-holes and large craters, and general maintenance work.

The men must work with their arms beside them, and sentries will be posted when there is a possibility of enemy interference, so that those at work may receive warning and defend themselves. If the use of poison gas is being resorted to, they must wear their respirators in the alert position, regardless of the fact that this impedes the progress of the work. They will often be required to work for long hours under the most trying conditions, in order that either a retreating enemy may be effectively pursued, or a retirement carried out without congestion of traffic and in an orderly manner.

37. *Typical example of forward road system.*

The map (Pl. **21**) shows a portion of country in France occupied by a division holding a short front and forming part of a large force during the War, 1914–19. In such cases of concentration, the actual length of front line trench apportioned to the division is very short, and the divisional area may increase in width towards the rear; the units are distributed in depth, in support and reserve trenches, and in billets, where such are conveniently available; their transport lines are situated in camps as near the main roads as possible and as far forward as is considered safe for the animals. The R.A.S.C. units are encamped within reasonable distance of the rail-head, in order that their animals may not be unduly worked in drawing supplies for the troops. It is important that a good road should serve the rail-head for this purpose, and the position of the latter will usually be determined by the road facilities available. The case illustrated is of the most difficult type, as the direction of approach to the divisional front is oblique, and movement to and fro must take place across the front of the formations on the right; these conditions always result in greater congestion of traffic, as many of the roads must inevitably be used by neighbouring units. The road problem in forward areas is much simpler when the direction of approach is at right angles to the line held.

The roads shown are main roads of either macadam or pavé, or a combination of pavé centre and macadam margins; with one exception they were the original country roads which were improved and widened to meet the increased traffic, and the manner in which the choice of sites for the various headquarters, parks, and dumps was governed by them is clearly indicated. The exception referred to is the length between the points A and B, which was an entirely new double-way macadam road, constructed on the site of a mud farm track to give a main approach road through the corps area, and to give direct communication between a convenient railway station with sidings and the forward troops. (*See* Pl. **22**.)

Owing to the fact that the enemy had exceptional facilities for observation from high ground on all sides, traffic during daylight was only allowed to use these roads as far forward as the line CC, and maintenance in rear of this line was carried out by corps and army troops. The line EE was considered as far forward as horse transport could normally be sent. The communication trenches and trench tramways commenced near the points F, G, and H, and ended in the vicinity of the front line.

As soon as orders to prepare for an attack were received, the question of supplementing the existing roads and relieving them of horse transport became imperative, and work on a cross-country track was at once commenced (shown by a dotted line on the map). This had its origin near the point B, and, avoiding the village (divisional headquarters), crossed the main roads as shown, and, on reaching the point D, bifurcated into two branches, arriving at the road EE near the points G and H. It was an earth track, with fascines and *corduroy road-mats* laid over the softer ground, small timber bridges at the crossings of the larger streams, and timber box-drains at the ditches; it was of double width throughout, and marked by a double line of white pickets wherever necessary. Signboards were erected at all important junctions and crossings.

As the date of the attack approached, the continuation of these two branches of the track towards the front line from the points G and H was proceeded with by night, and a third track was provided branching from the northern bifurcation at the point K, giving a means of approach to the extreme left of the divisional front, the intention being that these three tracks should be simultaneously continued across the intervening soft and heavily shelled ground at the earliest possible moment, and joined together at some convenient distance within the enemy's lines according to the penetration achieved.

When the attack was launched, parties and stores were accordingly in readiness to carry out this work, which was successfully accomplished in a few hours, the points L, M, and N being reached, and the junction effected on high ground some thousand yards within the enemy's evacuated positions; the field batteries were thereby enabled to advance and take up new positions in a minimum of time, and, within five hours, thirty wagon loads of engineer stores were able to be unloaded at the three field company dumps for use in the work required on the consolidation line, where the troops had reached their objective.

Simultaneously with this work, parties were working on the old main road between the points R and S with the intention of joining our main road system with that of the enemy as quickly as possible; this road was entirely obliterated throughout the greater portion of its length, owing to the very heavy bombardments to which the enemy's position had been subjected prior to the attack, and several diversions were necessary to avoid mine craters and large shell-holes in the neighbourhood of the enemy's front line. The more undamaged lengths were repaired with road-metal which had been previously dumped in the village near the point R, while the lengths over the obliterated portions, and the diversions above referred to, were dealt with by laying a double-way plank road. The advance in the initial stages of the attack did not penetrate sufficiently far to admit of a junction at the point S, and the first efforts were concentrated on making good this road as far as the high ground near the point L. This was quickly accomplished, and a road opened to traffic of all kinds as far as this point in about two days, which was afterwards continued to complete the junction at S in the later stages of the operation.

The above example is given as typical of the work required on a short length of the front in a large operation carried out in a civilized country with the maximum of concentration and with all classes of vehicles taking part; the procedure must necessarily vary according to local conditions, but the governing principles are the same in any theatre of war.

38. *Road screens.*

1. **Employment of screens.**—Screens are employed for the purpose of concealing roads, tracks, and other important works from direct enemy observation. The erection of screens on forward roads will rarely be necessary, as operations will have already commenced when such road-work has been undertaken, but existing roads and tracks in rear areas, where there is much daylight traffic, will require screening when they are under enemy observation, both as a precaution of safety and to conceal the extent of concentration which is takfng place. They are also of use

in encouraging the enemy to waste ammunition when there is nothing to hide.

There is no doubt that, if screening is carried out on a comprehensive scale and with a continuous policy, localities which, being under observation, would normally be subject to deliberate shelling become practically immune. This immunity does not depend on the invisibility of the screens erected, but on their distribution.

In every case, before a scheme of screening is settled, the ground should be carefully reconnoitred to ensure that every advantage is taken of its natural features, and that, as far as possible, there is assimilation of colour to local surroundings and background. Straight lines are usually more easily distinguishable than broken ones, so that irregularity of the top of the screens may be of value.

It is advisable to consider well beforehand, in the summer months, what screens will be required in the winter when leaves have fallen, and to have them erected before the natural cover disappears.

2. **Conditions of effectiveness.**—To be effective, screens should fulfil the following conditions :—

(i) The materials should be as light as possible for convenience of carriage ; at the same time, the construction should be sufficiently strong to resist weather and wind, and should not be liable to extensive damage by shell fire. They must be capable of easy and rapid erection.

(ii) The whole surface of the screen need not necessarily be opaque, but a sufficient proportion of the surface should be formed of opaque material to ensure that the screen as a whole conceals movement from the nearest hostile point of observation.

(iii) Whether the screens should be arranged so that they are not likely to be recognized as such, or whether it is of vital importance to render them inconspicuous, is a matter for decision in each particular case.

3. **Siting of road screens.**—Roads running at right angles to the front are best screened by hanging vertical screens across the road between trees, houses, or poles (*see* **Pl. 23**).

Roads running more or less parallel to the front are screened by siting the screens at least 50 yards from the edge of the road, in order that shell fire directed at the screens shall not cause damage on the road and *vice versa*. Such road screens require to be made specially high, but, at the same time, the lower edge can usually be some distance from the ground. Short lengths of about 30 yards placed in echelon, and overlapping each other, as shown on **Pl. 24**, are preferable to long continuous screens. This method permits of plenty of passage ways, limits damage by shell fire, and further the line of route screened, not being defined, becomes difficult to range on.

Roads at an angle to the front can be concealed by screens facing the front and arranged in echelon (*see* **Pl. 25**).

When erecting road screens it is important to prepare long stretches flat on the ground, and then in one night to erect all the screens ; progressive erection night by night invites shelling and casualties.

4. The details of the :—

(i) Various types of screens,
(ii) Manufacture of screens,
(iii) Erection of screens,

are given in Secs. **65** and **66**, M.F.W. (All Arms), to which reference should be made.

CHAPTER VII.

MOUNTAIN ROADS.

39. *Special considerations.*

1. **Importance of location.**—The topographical considerations affecting the choice of route for a road in mountainous country have been referred to in Secs. **3** and **11**. It is impossible to lay too much stress on the importance of careful survey, and the discomfort experienced by the users of many mountain roads can be generally entirely traced to careless and haphazard methods of location. If the best possible alignment has been carefully chosen, the principal difficulty to be encountered will have been overcome, and the construction of the road may be proceeded with.

2. There remain, however, certain special considerations in connection with the work of construction which must now be discussed. Whenever steep sidelong slopes have to be traversed, which in many cases become precipitous as the higher altitudes are reached, *masonry parapets* and *retaining walls* will always be necessary, in order to prevent accidents to traffic and to preserve the roadway itself. Constructional details of these are given in Secs. **42** and **49**. Retaining walls will also be necessary on the uphill or inner side of the road wherever there is a danger of slips. Curves are often of short radius, and where sharp corners are unavoidable the road must be widened, and a parapet wall will generally be required on the downhill side.

Special precautions against flood water must be taken. The effect of heavy rains and melting snow is very rapid, and a small stream may become a torrent in a few hours ; it is, therefore, necessary that catchment areas should be carefully studied, and sufficient waterway allowed in all culverts and bridges. The construction of catch-water drains becomes of paramount importance on mountain slopes. The planting of trees on the upper slope, in order to reduce the scouring action of rain, is often resorted to as a precautionary measure in unstable ground. It will also be necessary to protect the ground on the downhill side from the scour caused by spill water from the road ; trees and bushes will hold the ground at the toe of newly formed banks.

Provision against avalanches and snow must be made in all places where danger is anticipated from these sources.

The *supply of water*, both during construction and for the convenience of travellers, must not be overlooked ; it is generally necessary to provide drinking facilities for men and animals at intervals of every five miles along the route. Water-troughs should be of galvanized iron, masonry, timber, or concrete, as convenient, and should be arranged in series for men and animals.

Camping grounds are also essential on long roads, and, since these should be at a similar distance apart, their sites will often be determined by the position of springs and streams when conditions of ground permit.

Halting places should be arranged on narrow roads exceeding five miles in length, both for resting fatigued animals and to allow traffic to pass in opposite directions. These should always be placed on as nearly level ground as possible. Advantage should be taken of any plateaux which may occur contiguous to the road, and access given to them for traffic in both directions.

Sidings must be constructed as nearly as possible on level ground at intervals of every two miles, if the road is being constructed for use by mechanical transport. They should not be less than 66 feet in length and 16 feet in width. Sidings located on the uphill side of a road should be provided with a side drain connected to the road side drain. All halting places, sidings, and depots should be soled and metalled up to the edge of the road in a similar manner to the roadway itself.

Stacks of metal of the proper trapezoidal shape should be placed in special places, cut out of the uphill road banks. A definite amount should be stacked in each case ; 2,000 cubic feet per mile is a suitable quantity to allow for ordinary maintenance.

3. **Instructions.**—In exceptional cases and in work undertaken in great haste which has to be completed in the shortest possible time, the engineer detailed to carry out the construction of the road will also be responsible for the design, but in most circumstances he will be given instructions and specifications regarding the work to be done. These may be either of a special nature concerning only the particular road, or they may be issued in the form of a general specification from which he must extract such rules as apply to the particular case. Such instructions will refer to width, ruling gradient, cross-section, surface drainage, curves, culverts, bridges, &c.

The Military Works Directorate, Quartermaster-General's Branch, Army Headquarters, India, issue general specifications for military roads ; these specifications, as well as circulars regarding details, can be obtained by all officers serving in India. The principles contained in this chapter are based on general specifications which have from time to time been issued.

40. *Cross-section of mountain roads.*

1. **Width.**—The width to be given to mountain roads will largely depend on the type of traffic for which the road is intended. Useful figures are given in Sec. **10**, but, as these refer to road construction during operations, they should be regarded as the minimum permissible. The increasing use of mechanical transport renders the provision of ample width essential, and any road of a permanent type should not be less than 20 feet wide, clear of side drains and parapets. In India, the width of roads is as follows :— On the plains 24 feet, in the hills 20 feet, on embankments 27 feet, all in the clear with an additional 4 feet at corners.

2. Camber.—The same rules as given for roads in flat or undulating country are generally applicable, but there is considerable controversy regarding the means by which surface water may be got rid of on sidelong ground. It is essential that all such water should pass off as rapidly as possible. Many engineers favour a uniform slope towards the inner edge. It may be said in favour of this method that all water thereby drains into the gutter instead of flowing over the outer edge without proper means of discharge, and that the super-elevation reduces danger to traffic. On the other hand, it is contended that heavy traffic, tending to cut the corners, is liable to damage the inner gutter and cause blockages which result in the collection of pools of water in wet seasons ; also that traffic will tend to hug the inner side of the road and produce uneven wear, until finally the gutter spreads on to the road surface which is scoured out into a considerable watercourse. Experience is generally in favour of a barrelled cross-section on a permanent road. The camber allowed should not be greater than 1 in 40, *i.e.*, in a 20-foot road the centre should be 3 inches above the edges of the side gutters. On steep gradients it is sometimes advisable to increase the camber in order to confine water running down the slope to the gutters as much as possible ; if running water is allowed to spread over the surface of the road, rapid disintegration follows. The camber should in all cases be given to the subgrade and the metal should be consolidated to a uniform thickness over the formation, for if the latter is made flat the finished surface will quickly become hollow in the centre. When laying out round curves, the outer half of the road should be banked up, giving a uniform slope from the outer to the inner edge of the road ; for a curve of 35-foot radius the maximum slope is 1 in 10. In addition, a parapet wall, say, 2 feet high and 1½ feet thick, should be provided.

3. Section on sidelong slopes.—Wherever the location of the line will permit, as much of the road as possible should be made in cutting, but, to save the great expense of rock cutting, half the road, and sometimes more, is usually built up. Direction, slopes, and curves will, of course, receive the first attention of the engineer, with the result that a properly designed road will sometimes be in cutting and sometimes in bank, and to locate it so that the major portion will be in cutting would necessitate considerable deviation from the line fixed by the usual methods of survey, while the length would be increased out of proportion to the advantage gained. The excavated material should be used to form the outer portion of the road, and for the protection mound or bank required at the approaches to the cross-drainage works at the re-entrants. The cost of rock cuttings and retaining walls will be compared, and a decision thus arrived at as to the most suitable cross-section for the locality under consideration.

The constructional details involved in the building of a road on sidelong slopes can best be studied by reference to illustrations ; **Pls. 26** and **27** show various types of cross-section for different slopes and soils.

Retaining walls are required :—

(i) On the edge of precipitous places where there is no room for a bank.

(ii) Where a bank would be of excessive length in section, owing to the angle of the natural ground slope approaching the angle of repose of the material.
(iii) At all re-entering curves, and where there is cross-drainage.
(iv) Where a wall would be cheaper than a bank.

The principles governing their construction are discussed in Chap. VIII.

Embanked roadways are particularly liable to settle or slip away altogether under heavy rain, and to give the embankment a good hold the natural surface should be cut in steps, as shown on Pl. **14**, Fig. 2, and Pl. **26**, Fig. 3. In repairing the slope of embankments, the old earthwork slopes should be stepped before fresh earth is thrown on.

41. *Drainage of mountain roads.*

1. The inner gutter.—The dimensions of the inner gutter on sidelong ground will be governed to a certain extent by the local conditions. An inner gutter must be sufficiently large; a good average width is 3 feet, and it should be about half as deep as it is wide. It must be borne in mind that this gutter has to carry off the surface water from the ground lying between the road and the catch-water drain above it. In hard rock, gutters need not be paved, but in soil, rough stone paving is necessary. On slopes, it is desirable that the scouring action of running water should be checked by putting in at intervals 2 or 3 courses of cross setts, which will decrease the depth of the drain by a few inches.

Where abrupt salients occur on a slope, the inner gutter should be carried round the curve in a culvert, otherwise there will be a great tendency for the inner berm of the road to be scoured out, owing to the rush of water down the hill in heavy rain; this culvert should commence near the tangent point of the curve on the uphill side of the salient. As an alternative, inner gutters can be continued along the tangent and taken under the road, so as to discharge with a straight course over the lower slope.

2. The outer gutter.—If the drainage on the uphill side of the road is properly dealt with, the outer gutter is only required to take water from the outer half-width of the road surface, and, consequently, its dimensions need only be about one-fourth of those of the inner gutter. A width of 9 inches and a depth of 3 inches should suffice to meet all ordinary requirements. In hard rock, a depression in the surface, close by the foot of the parapet or other protection, will suffice.

The water collecting in the outer gutter should be let off through the parapet or earth protection mound by drainage-holes or channels at frequent intervals, and it is a useful plan to place the guard stones actually in the side gutter and immediately below the drainage-holes, thereby deflecting the water through the latter. Where guard stones are necessary at more frequent intervals than drainage-holes, the gutter should pass behind them. The outer gutter will seldom require to be paved in mountain roads.

3. Cross-drainage.—The natural surface drainage of the hillside is discharged by means of watercourses, which may be permanent or intermittent streams. Nullahs or khors are watercourses which are dry during the greater part of the year, but which are flooded with enormous force after heavy rain. A road following the contours of the hills will cross these watercourses in turn, and the water may either be taken under the road or over its surface.

Cross-drains under the road may be of the following types :—

(i) Permanent bridges or culverts.
(ii) Dry stone culverts.
(iii) Corrugated iron or reinforced concrete piping.
(iv) Percolating causeways of large boulders.

Water may be carried across the road by :—

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

In all important roads, cross-drainage should be taken under the road and at right angles to it ; cross-drains constructed obliquely will be longer and more difficult to build on account of their skew ends. The floors should have a longitudinal slope equal to the slope of the water-course, and must be paved wherever there is a danger of scour ; in such places there should be a stone or masonry apron to carry the discharge safely down the lower slope. Catch-pits must be dug at the head of all cross-drains to collect rubbish and prevent scour. The bottoms should be one foot, or more, below the level of the floor or sill of the cross-drain. They must be lined with stone or masonry in soft ground. (*See* Pl. **39**.)

4. Catch-water drains.—These have been referred to in Sec. **17**, but it is obvious that, with steep slopes and rocky surfaces, much greater attention must be given to them than is necessary in easy country.

They should be cut from 15 to 30 feet above the road to intercept water from the higher slopes.

These drains should, in plan, take the form of an inverted V with their apex above the watersheds of the salients, from which they will fall away, and should discharge their water into the ravines to be carried below the road by means of the cross-drains. In soft ground they must be pitched with stone and banked up on the downhill side. The size will depend on the rainfall to be dealt with, and on the extent of the catchment area which they serve ; it facilitates drainage in long catch-waters if the dimensions of the drain are gradually increased towards its lower end. On some mountain roads where the rainfall is excessive, catch-waters 25 feet wide and 5 feet deep have been constructed, and they should seldom be less than 6 feet wide and 2½ feet deep. Pl. **28** shows the general arrangements of mountain road drainage.

42. *Rock cuttings and precipice work.*

1. Cliff roads.—Wherever a road has to be taken along the side of an almost vertical cliff, a very careful examination must be made of the stratification of the rock before the section of the road and the method of cutting it can be decided on (*see* Sec. **11**). Want of care or judgement on this point will result in great danger to the workmen, and very probably in the loss of life.

If the strata slope downwards into the hillside, as on Pl. 2, Fig. 2, the rock may be permitted to overhang the road, forming a *half-tunnel*, provided sufficient headroom is allowed ; but, as the work proceeds, the rock must be constantly and carefully examined to note the presence of fissures, either natural or caused by blasting.

If, on the other hand, the strata run down out of the face of the cliff, as on Pl. 2, Fig. 1, it will be necessary to cut back until the inner slope is at a safe angle to prevent slipping. In such a case the blasting and cutting must be commenced from the top and worked downwards until the required level is reached; this procedure is known as *cutting-down from the top.*

Pl. **29** shows a military road constructed along the face of a precipice.

2. **Half-tunnels.**—These can only be made with safety when the rock is hard, sound, and free from fissures. Pl. **30,** Fig. 1, shows a section of a half-tunnel. The rock is blasted out from a lodgement formed about 20 feet above the intended road level and dressed off, the cliff being attacked either from the face, or from one or both ends. Pl. **30,** Figs. 2 and 3, illustrate the methods of drilling the bore-holes.

3. **Cutting-down.**—If the rock is at all soft or loosely stratified, the cutting must be commenced at a point on the hillside as far above the formation level as will allow of sufficient batter being given to the inner slope, and the rock removed down to the road level, which should be clearly marked on the cliff face by whitewash or other means. An alternative to this method is to blow out as much of the cliff face as is necessary by firing large mines, and then to dress back the slope to the required batter. An illustration of this type of section is shown on Pl. **27**, Fig. 3.

4. **Blasting.**—In all cases, except where the softest rock is met with, the use of explosives will have to be resorted to in order to form a cutting: full details regarding their employment are given in M.E., Vol. IV. Portable drilling plants will be found extremely useful for this work, provided that the skilled personnel required for their manipulation are available. Only specially trained men should be employed on blasting work, and the best possible supervision should be exercised; charging, tamping, and firing should be carried out by Europeans.

Dynamite or blasting gelatine are the explosives generally found most suitable for use with small bore-holes. These, however, freeze at temperatures below 4° C., and must be carefully handled and thawed in order to obtain the maximum results. For shaking rock, ammonal is a very suitable explosive, but when this is not available amatol may be used. If the stone to be removed is required to be dressed and used in masonry work on the road, black powder should be used, since the action of a low explosive will dislodge it in larger fragments.

A cliff face may be sometimes easier to attack by means of concentrated charges than by a series of small bore-holes. Galleries should be driven into the face of the cliff to a depth equal to the required width of road, and the mine charges placed in chambers formed at right angles to the ends (*see* M.E., Vol. IV, Sec. **34**).

5. **Parapets.**—Stone parapets must be erected where the road runs along the side of a cliff or round the outer edges of most curves. They are usually continuations upwards of dry stone retaining walls, and should not be less than 3 feet in height.

Low parapets and iron guard rails may be erected on less dangerous slopes if such practice will prove more economical, but on precipitous slopes animals are less likely to take fright when a continuous wall is provided. Wooden rails should be avoided as they give a false sense of security, and will never stop a runaway. Masonry parapets should be 1½ feet in thickness. Dry stone parapets may be 1½, 2, or 3 feet thick, according to the nature of the stone: the stones should be carefully set, and each course should be built through the wall. Copings which need not necessarily be laid in mortar, or a cap of earth should be added, and they should follow the grade of the road. Frequent openings for drainage are necessary; the position of drainage openings through a parapet wall must be carefully marked before the building is commenced. All parapets should have guard stones wherever necessary, particularly on curves.

6. **Cliff galleries.**—Where the time available does not allow of blasting and tunnel work, cliff galleries and cradles are resorted to for the negotiation of cliffs and precipices.

Pl. **31**, Figs. 1 and 2, show types of cliff galleries for foot and pack traffic. They are troublesome and dangerous to construct, but afford the simplest and cheapest arrangement where the strata are suitably inclined. It is important that the strata should *dip* or be inclined inwards from the face, in order to ensure safe attachment for the jumpers and holdfasts.

The roadway is formed of chesses supported by road-bearers, which in turn rest 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 from the top to the proper level, one or two men armed with crow-bars and jumping tools, with which holes can be made for jumpers or timbers.

If the top of the precipice is inaccessible, it is necessary either to scale from below, or to work forward from the furthest point of the road, a log being projected forward beyond the end so as to provide a platform from which the holes may be drilled, and the supports fixed a few feet in advance.

Another method is to pass two cables along the face of the cliff from two accessible points on the proposed line of the road, one acting as a hand cable, the other for foothold, which is obtained by means of a double stirrup or small suspended platform upon which a man can stand and work. These cables must be strained until the man is at the right height for his work, and kept at that tension while the work is proceeding.

When boring is not practicable, a light roadway may be carried on timber cradles suspended by means of wire cables from jumpers driven at the top of the cliff (*see* Pl. **32**, Figs. 1 and 2); the cross-bearers of the cradles should tilt upwards, otherwise, when the cradles draw away from the face of the cliff and lean forward under traffic, the surface will slope outwards and become dangerous.

Pl. **33** shows a more permanent type; the dimensions given are suitable for horse transport and light motor cars. The design may be modified to suit traffic requirements, but galleries of this nature are not recommended for heavy traffic.

43. *River causeways and fords.*

1. When lasting bridging materials are not available, it is better to be content with crossing a small waterway by a safe *causeway* or *ford* than

to attempt cheap bridging; a substantial bridge can be provided later when funds permit.

2. **Causeways.**—On continuous mechanical transport roads, causeways across nullahs are only admissible in place of bridges when traffic is not stopped by these nullahs being in flood. On occasional mechanical transport and cart roads they may be provided where a depth of more than 1 foot of water is not likely to last for more than 24 hours.

The type of causeway to be constructed depends on the length of time during which the work will be used. If it is only required as a purely temporary measure any temporary arrangement will suffice, such as the use of the nullah bed cleared of boulders, or the construction of a raised causeway, as shown on Pl. **34,** Fig. 1, or the sinking of large boulders beneath bed level and filling up to bed level with broken stone. It must, however, be remembered that the first flood will sweep away any raised embankment, so the first or third methods are preferable. No raised embankment should be put in, if it is intended subsequently to construct a permanent causeway.

If it is intended to use the work permanently, a more elaborate type of causeway must be adopted.

The preliminary work is :—

(i) Ascertain level of maximum flood known from observation of flood water, by local enquiry or by calculation from catchment area.

(ii) Make a longitudinal section along centre-line of nullah, from ¼ mile above site to ¼ mile below.

(iii) Make a detailed survey of nullah for ¼ mile above and below site.

(iv) Make a cross-section of nullah at site.

The points to be observed in designing are :—

(i) Design the surface of the level portion exactly at true bed level, as ascertained from the longitudinal section. If it is higher or lower the regime of the nullah will be altered during the first flood, and serious permanent silt trouble will be the result.

(ii) Design the level portion so as to be as long as possible compatible with the slope of the ends not being greater than 1 in 14 (if possible, a slope of 1 in 20 should be aimed at).

(iii) The cross-slope should correspond with the fall of the nullah, subject to a maximum of 1 in 30.

(iv) The causeway must be as nearly as possible at right angles to the nullah.

(v) In long causeways there should be angle iron posts built into the down-stream wall at 100 feet intervals, and painted white with broad lines of different colours to mark the depth.

(vi) Pl. **34,** Figs. 2 and 3, show a plan and cross-section of a permanent causeway in full detail. No less elaborate design will permanently withstand the heavy floods which are inseparable from a mountainous district.

A wire crate mattress or apron, 1 to 2 feet thick, made of stout galvanized wire with a 6 to 9-inch mesh and filled with boulders has been found very useful as a remedy for overcoming scour which has developed at the down-stream side of a causeway, for use as a temporary causeway in shingle nullah crossings, and for controlling the current.

3. **Fords.**—The approaches to a ford should be given a very gentle slope to the water's edge, as the road at these places should be as easy as possible; they should be as broad as possible, so that the traffic will not be obstructed by one wagon breaking down.

Horses and cattle, after crossing a ford, carry water dripping from them for a considerable distance along the road, and keep it constantly wet. It is, therefore, of great importance that the adjacent road should be metalled and very well drained before traffic is allowed on it.

If the river is broad, the position of the ford should be marked by stakes or buoys. 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.

4. **Irish bridges** may be temporarily used to take drainage water across a road when it is found impossible to obtain material suitable for the construction of a culvert. They consist of a broad shallow channel paved with squared rubble stone setts.

An Irish bridge is well suited to a fairly level road, but should never be constructed on a steep gradient, as it then forms a sharp ridge in the roadway which is inconvenient for wheel traffic, and the stones get quickly loosened and kicked up. If employed, it should be constructed at the foot of the slope, and the water led up to it by side drains. An Irish bridge should always be placed at right angles to the line of traffic, and should never be used on first-class roads or where mechanical transport is to be expected.

Pl. **34,** Fig. 4, shows a section of an Irish bridge.

44. *Snow, avalanches, and landslips.*

1. **Snow** must be reckoned with at high altitudes. In the higher latitudes of India it will be practically permanent at 8,000 feet above sea level.

Mountain roads through high passes, which have to be cleared in the spring when the winter snows begin to melt, are often difficult to locate in the absence of telegraph poles, especially where the track doubles back or zigzags up a mountain side. But it has been observed that light will be reflected at a slightly different angle from the snow overlaying the track, however deep, owing to its sinking as the roadside drains discharge. The difference can be easily 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, from an engineering point of view, may happen to be through a ravine so sheltered from the sun that the snow will remain unmelted for weeks longer than on another but less favourable route, and so block the road for a longer period; in such circumstances the less favourable approach must be chosen.

The usual precaution taken to prevent the formation of drifts on roads is to erect high close fencing across the direction of the prevailing winds at a sufficient distance from the edge of cuttings liable to be blocked, so that the snow will be piled up on the windward side and not extend on to the roadway. As a rule, deep cuttings through knolls and isolated hills require no protection, because the greater portion of the snow will be blown round the base and not over the hill.

High stone walls are used in some countries for the protection of railways. Pine and fir hedges are planted in Russia for this purpose; they are placed in rows at from 150 to 175 feet distance from the track.

2. **Avalanches.**—Places where these have occurred should be avoided, if possible, as they are certain to occur again. If these spots must be passed, snow sheds should be built.

Pl. **35** shows useful types of snow sheds. The slope of the roof should coincide with the natural slope of the mountain side, in order that the mass of snow, earth, or stones may slide off it. It is not intended that the design should be strong enough to support a dead weight, and the roof should be of such material that the mass will continue to slide on it; corrugated or plain galvanized iron is useful for this, as it presents a smooth surface. Fig. 1 shows the procedure adopted in the Caucasus, which is to have two routes, one covered and one open; the latter is used when the route is clear of snow or after avalanches have fallen. If the slope of the roof is correct, the debris will invariably be carried over the outside track.

Another method of dealing with avalanches is to prevent their development by building cross-walls in herring-bone plan to overlap along their track, so that the debris falling on one is deflected and becomes piled up behind the next.

3. **Landslips** are generally difficult to deal with; they are due to several causes, such as springs, faults in strata, frost, and careless excavation.

It is generally better not to attempt to check a slip of earth overlying rock, but to encourage it by adding water; this will leave the rock exposed, and the danger of a slip occurring is removed once and for all. Irresistible landslips which foil all remedies must be left to work out and settle of themselves in the course of years.

An emergency remedy, in rocky strata, is to build a retaining wall at the toe of the slip, and to divert any water which may be causing trouble away to either side. If the strata are loose a wall should be built at the foot of the bank, and the slope should be cut back in terraces, the steps being revetted with fascines and pickets or turf; grass shrubs and small trees should then be planted on the terraces (*see* Pl. **31**, Fig. 3). Shale and clay slips are the most troublesome, and it is often impossible to stop them. If a clay or shale slip occurs during wet weather, it is often expedient to clear away debris and wait until the dry season, when a stout retaining wall should be built with dry stone packing behind it and adequate drainage over the top. This will hold up any further slips. Another plan is to burn the clay *in situ* with an admixture of fuel, as in a brick clamp. The resulting clinker can then be dressed down to a suitable slope.

Slipping nullahs or watercourses are best arrested by cross-walls constructed of the heaviest stones possible, built at short intervals, and projecting just above the level of the watercourse bed; no small stones should be used, as water must pass freely through the interstices. These are not meant to act as retaining walls, but to arrest and reduce the water velocity.

If a road is breached by a slip it should be bridged at the same site; on no account should the alignment be altered by cutting back into the hillside.

45. *Labour for mountain roads.*

1. Where nothing but European labour is to be used, the work will be organized and carried out, either by direct labour or by contract, on the lines laid down in "Regulations for Engineer Services, Part I," but where native labour is to be employed, special arrangements must be made for its handling. The procedure adopted in certain cases on the Indian frontier, and described below, will serve as a guide for the organization of military road-works under similar conditions.

2. **Coolie corps** are sometimes raised, each having a strength of about 1,000, and commanded by engineer officers, of whom there should not be less than three, with three or four picked European or native subordinates with linguistic qualifications. The coolies are organized and despatched in batches, each under an officer, to the chosen base. Their organization requires considerable forethought as to equipment, food, and transport. Waterproof sheets and light tents must be carried by the coolies themselves, and a reserve of these should be available at an advanced base. Huts can be erected at depots, formed later as required.

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

1 field engineer in charge, with office establishment, head store-keeper 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, each controlling and supervising 500 coolies and three or four sections of road.

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

Duties of staff.—The field engineer should be responsible for all organization and arrangements, viz., accounts, correspondence, medical services, commissariat, transport, stores, tools, and plant (*see* Appendix IX); to his personal assistant he may delegate supervision of a portion as convenient. He should control and supervise the work as a whole, delegating sections of it to the assistant field engineers, according to the nature of the work and their capacity.

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

Overseers, sub-overseers, and head masons must always be on the works to give levels and bench marks, supervise blasting works, &c., and to see that all orders are satisfactorily carried out. Assistant store-keepers will be required at tool depots, one to each assistant field engineer and magazine.

Supplies.—The senior officer in charge may have to arrange for the supply of food and issue of rations, not infrequently at short notice, with the aid of an inexperienced staff; he may possibly, in addition, have to organize his own transport (coolie and pack), and to find forage for it. If operations are proceeding, or are about to proceed as soon as the road is fit for the passage of troops, a definite understanding, *in writing*, should be arrived at with the G.O.C. regarding supplies, as the supply and transport corps may otherwise be unable to meet the demands of non-combatants. As an example of what may be required in this direction, it may be stated that in the Tibet expedition 2,400 lbs. of food were consumed by each 1,000 coolies *per day*; as many as 3,400 were catered for, which meant over 3½ tons, or over 100 loads, for food alone daily, and, in addition, a similar weight of tools. A transport coolie carried an 80-lb. load per day over a 5-mile stage, and a pack animal twice this weight over the same distance. The normal coolie load should, however, be taken as 40 lbs.

A list of the tools required for native labour is given in Appendix IX.

CHAPTER VIII.

MASONRY STRUCTURES IN ROAD-WORK.

46. *Introductory.*

1. The masonry structures involved in road-work consist of bridges, culverts, retaining walls, &c.

Important bridges with spans greater than 20 feet, required in connection with a new road, are normally built at the same time as the latter by parties specially detailed for the work. During operations the new structures will often be of timber, steel joists or girders, &c., since the limited time available will generally preclude the employment of masonry (*see* M.E., Vol. III).

The labour employed on the road construction will, however, usually undertake the construction of small bridges and culverts, and the strengthening and repair of those existing.

2. **Bridges.**—Masonry arches are discussed in Sec. **51**. *Waterway* and *scour*, which affect the design and construction of masonry bridges and culverts are dealt with briefly in Secs. **47** and **48**.

Approaches to a bridge on an embankment should be constructed as soon as possible to allow of settlement, the necessary top dressing and camber being added later before the laying of the soling and metal.

3. **Culverts** are discussed in detail in Sec. **50**.

The principal materials used in building culverts are stone, stone slabs, timber, corrugated iron tubing, concrete and steel joists, and reinforced concrete pipes. For small drains, earthenware pipes may be used; square timber *box-culverts* of 2-inch or 3-inch planking are extremely useful and rapidly constructed.

4. **Retaining walls** are briefly discussed in Sec. **49.** Reference to M.E., Vol. I, should be made for further information.

5. **Repairs to bridges.**—In country which has been vacated by the enemy, it will generally be found that bridges have been destroyed. A thorough demolition will usually necessitate the construction of a new bridge, in which case a temporary road and bridge deviation may become necessary, but in many cases where the destruction has been hastily carried out repairs can be executed. It is of great importance that the erection of additional piers does not materially reduce the waterway of bridges; partially destroyed abutments and debris should be removed. Pl. **36**, Fig. 1, shows a method of repairing a short span girder bridge.

Where bridges have to be strengthened to take heavy artillery and tanks, additional steel joists may be added. Masonry arches may be strutted with timber (*see* Pl. **36**, Fig. 2), or steel joists embedded in concrete may be laid over the arch ring, after the abutments have been strengthened with concrete.

The strengthening of culverts must not be overlooked; they should never be filled in unless the streams or ditches can be diverted.

47. *Calculations for waterway.*

1. **Factors affecting waterway.**—Wherever a very long road or railway embankment has to be constructed on a site where it will form an obstacle to the natural flow of surface water, there is considerable risk of damage by flood water, unless adequate waterway is provided for passing off the flood discharge. Similarly with roads in hilly and mountainous country, the provision of waterways must not be overlooked. It is easy to construct bridges and culverts of such capacity that they will be safe against any flood if economy is not studied, but to arrive at a correct estimate for the necessary area of waterway which will suffice to meet the requirements of each case is not simple. The factors governing such an estimate are :—

- (i) The maximum rainfall over the *catchment area.*
- (ii) The permeability and degree of cultivation of the soil.
- (iii) The shape of the catchment area.
- (iv) The character and inclination of the ground surface, influencing the rapidity of flow.
- (v) The condition and inclination of the bed of the stream; whether it is clear or obstructed.
- (vi) Whether an *afflux* is permissible.
- (vii) Form of section of the bridge or culvert, and inclination of the invert.

Washouts will always occur, even after the best calculations and observations, unless the road-maker is an extravagant builder. It is cheaper to have a few washouts than to build unnecessarily big outlets.

2. **Catchment area.**—Every drainage area is separated from an adjacent drainage area by a line of high ground which forms a watershed, and the discharge through any bridge or culvert will include the drainage from all this area above the structure; this amount is spoken of as the *yield* of the catchment area.

The nature of the surface must be carefully studied, and the effect of heavy rain deduced from the natural conditions of each particular area; for instance, the flow from a barren rocky area with steep slopes will be very rapid, and will consist of a much higher percentage of the rainfall than will be discharged from a flatter area of permeable soil covered with vegetation. As regards shape, if a catchment area is long and narrow, the discharge from the lower or near portion of it may reach the site of the bridge before that from the higher ground arrives; on the other hand, if the higher ground has steeper slopes than that lower down and the area approximates more to that of a semicircle with its centre at the bridge, the flow from the different streams will tend to reach the main stream simultaneously. The shape of an area and the locality of its watercourse in relation to the main stream are of more importance in a large area than in a small one.

3. **Observations of floods.**—The estimation of flood discharge becomes a comparatively easy matter when reliable records are available for consultation; it will generally suffice to choose the highest flood which has occurred in the past twenty-five years, adding 10 per cent. for a margin of safety, and to calculate the waterway required on this basis.

If the records available do not cover a period of twenty-five years, the margin of safety should be increased, unless an abnormal flood has been recorded.

If records are absent or unreliable, inhabitants must be interrogated and flood marks searched for; in calculating from these sources of information, a substantial margin of safety must be allowed.

It should be remembered that, in tropical districts, drainage should never be estimated from the first floods of the rainy season, however severe; the absorption after the dry weather is considerable, and until the earth becomes saturated the full effect of the rains will not be felt.

4. **Calculation for culverts and small bridges.**—An approximate method for arriving at the correct size of a culvert is to compute the drainage area and make an opening large enough to carry off 3 or 4 inches of rainfall per hour; this may, at first, appear abnormal, but it will be found a satisfactory estimate in districts subject to heavy rains; 5 inches per hour has been laid down for one very wet district over areas not exceeding one square mile. In determining the sectional area of a small waterway, an error of 100 or 200 per cent. is of little consequence; the question virtually resolves itself into a choice between a 2 or 3-foot pipe or a 6 or 8-foot culvert.

Another approximate method of deciding the waterway of culverts and small bridges in hilly country, for catchment areas of from $\frac{1}{2}$ to 1 square mile in extent, is to allow 20 feet width of waterway per square mile of area. Thus for a catchment area of $\frac{3}{4}$ square mile a small bridge of 15 feet span should be adequate.

In the case of small culverts the passage of mud and stones must be allowed for, and no culvert should be less than 2 feet wide.

There are various formulæ for finding the area of waterway required for the discharge from a catchment area, but local conditions enter into the problem to so great an extent that it is impossible to lay down a definite rule. An estimate, based on previous floods and comparison with similar neighbouring areas, is necessary to supplement a decision arrived at by the application of formulæ, and an allowance for safety should always be made.

For estimating the cost of works, however, formulæ are useful, and the following well-known rules are given.

Talbot's formula :—

$$a = C\sqrt[4]{A^3},$$

where a = area of opening in square feet,

A = drainage area in acres,

C = 1·0 for very mountainous country with steep slopes ; 0·70 for hilly country ; 0·30 for undulating cultivated country.

Dickens' formula.—This is useful for estimating in country with a moderate rainfall of from 24 to 50 inches per annum :—

$$D = 825\sqrt[4]{M^3},$$

where D = discharge in cubic feet per second,

M = catchment area in *square miles.*

5. **Calculations for large bridges.**—To arrive at decisions regarding height, number of spans and length of each, nature of approaches and abutments, and the depth to which foundations must be sunk, the requirements are many, and the subject, being a large one, is beyond the scope of this volume. Reference should be made to the latest publications on this subject when information is required.

6. **Afflux.**—The erection of a bridge across a river contracts the natural waterway to a greater or lesser degree according to the design, and the result of such contraction is the raising of the water level on the up-stream side of the bridge. The amount by which this level is raised above the natural slope which the water would take in times of flood, if there were no obstruction, is called the afflux.

Consequent on the restriction of the natural waterway and the afflux produced there will be an increase in velocity, and this velocity must not exceed that which the natural bed of the river and banks can withstand without scouring resulting.

The amount of afflux which may be permissible must be decided before the waterway to be provided can be determined. If the land above the bridge can bear a certain submergence, an afflux is not detrimental, provided the river bed will stand it ; in very soft soil 4 inches of afflux should not be exceeded, while 3 feet may be taken as a maximum for a bridge on rock with substantial masonry piers.

The springings of all arches should be at least 1 foot above afflux level.

48. *Scour.*

1. **Relation between velocity and scour.**—It has been stated in the preceding section that the velocity in the neighbourhood of a bridge must be kept below that velocity which will cause scouring of the river bed and banks ; it remains to discuss the action of rapidly flowing water on various kinds of material, and the effects produced by the erection of obstacles such as piers and abutments in a watercourse.

☞ It should be remembered that the velocity at the sides and bottom is always less than the mean surface velocity of a stream ; *e.g.*, a surface velocity of 5 or 6 feet per second is equivalent to 3½ or 4 feet per second at the bottom.

The effect of different velocities of water in scouring various soils is given in the following table, which will serve as a useful guide, although it is not altogether reliable :—

TABLE E.—*Velocities producing scour.*

0·25 foot per second will scour	fine clay, river mud, or silt.
0·50 ,, ,, ,, ,, ,,	fine sand, or common clay.
0·75 ,, ,, ,, ,, ,,	coarse sand.
1·00 ,, ,, ,, ,, ,,	fine gravel.
2·00 feet ,, ,, ,, ,,	round shingle (1-inch stones).
3·00 ,, ,, ,, ,, ,,	large shingle (2½-inch stones).
5·00 ,, ,, ,, ,, ,,	conglomerate.
6·00 ,, ,, ,, ,, ,,	laminated rocks.
10·00 ,, ,, ,, ,, ,,	hard rock.

Chailby's formula for velocity of water which will move stones is useful :—

$$D = \frac{V^2}{85},$$

where D = diameter of stone in feet,
V = velocity in feet per second.

2. **Effect of obstructions.**—Scour develops in the first instance by the swirling action of the water forming a pot-hole. The chief aim of the engineer is to locate or predict this, and apply a remedy or take precautions against it.

A pot-hole occurs whenever an obstruction such as a bridge pier, abutment, or spur projects into the general current of the river so as to shield a body of water under its lee. The shielded body of water is formed into an eddy by the main current brushing past one side of it, and it is this swirling action which scoops out the pot-hole, and this must not be allowed to come dangerously near the foundations of such a structure. Pl. **37**, Fig. 1, illustrates the formation of pot-holes.

The action of scour is found to be the greatest when a river is rapidly rising or falling, and not during the period of full flood.

Again, scour may be greatest in an ice flood, when narrow spans are apt to produce blockages and force the current to undermine the foundations, and a similar action results from floating logs and wreckage getting piled up across narrow openings. For this reason, the piers of bridges are usually tapered to a point in plan ; the *cut-waters* are sometimes fended with piles, or, if the ends of the piers are rounded, a triangular boom of beams will serve the same purpose.

3. **Precautions against scour.**—The practical remedies to minimize or prevent scour are :—

(i) Take the river direct through a bridge opening, employing *bunds* or guide banks, if necessary, to maintain an even flow. To protect a long straight face of river bank loose pitched boulders (80–100 lbs. each) should be used ; a guide for estimating is to allow 300 cubic feet of stone per foot run of the bank.

(ii) Provide ample waterway, and leave no sudden obstacles or sharp bends.
(iii) Use deep well foundations for piers, and introduce abutment piers.
(iv) Surround the pier bases with an apron of stone 2 to 4 feet thick; this should be renewed or added to every year.
(v) Provide a stone-pitched floor or paving between the piers, or 12 inches of concrete or bricks in cement.
(vi) Provide drop walls on the down-stream side.
(vii) Where pot-holes occur it is only necessary to fill up the area with stone pitching or quarry refuse.
(viii) Secure a uniform depth in the waterway.

(v) and (vi) are only applicable to small waterways.

Pl. **37**, Fig. 2, shows an instance of wrong location of a guide bank, causing a pot-hole dangerously near a bridge abutment; a new guide bank was constructed, causing a pot-hole in such a position that the abutment was not threatened.

49. *Retaining walls.*

1. **General remarks.**—Retaining walls are designed to support the roadway on hillsides, or to hold up the ground above the road when it cannot be cut back to a safe angle, either on account of inability to procure the necessary width of land or for reasons of economy.

Localities where retaining walls are found necessary are :—

(i) At all re-entering curves and where there is cross-drainage (*see* Pl. **28**).
(ii) On the edge of precipitous places where there is no room for a bank, or where a bank would be of excessive length in section, owing to the angle of the natural ground slope approximating to the angle of repose of the material to be used to form it.
(iii) Where the bank slope and the ground slope are nearly, or quite, parallel to each other.

As a rule, when suitable stone is available, dry stone walls will suffice, except in particularly dangerous places, when masonry walls must be built. If masonry walls are used, weep-holes must be provided; they should be built in through the wall at 4-foot intervals and at every third course. The filling behind retaining walls should be of stone and chips whenever possible; if earth is used it should never be rammed, and stone filling should be packed immediately behind the wall to assist drainage. In constructing dry stone walls, particular care must be taken to ensure that the proper bond is obtained, especially when stone possessing no natural cleavage is being used. There is a tendency among masons to sacrifice strength to appearance by choosing stones with one square face only, which results in a very weak wall with a good face appearance; it is, therefore, essential that strict supervision should be exercised.

The courses should be laid longitudinally horizontal throughout the length of the wall, from the outer to the inner face, long headers being used to give through-bond; the stones should be inclined towards the back of the wall so that they are perpendicular to the batter of the face.

The ground at the toe of the wall must be protected by stone pitching, in order that there may be no danger of slipping through disintegration by drainage water. High walls require a good masonry foundation 2 feet thick; walls over 12 feet in height should have courses of masonry in mortar at every 6 feet.

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

In soft or yielding ground, the pressure on the foundations should be distributed over a greater area and its intensity decreased by means of stepped footings. Rock of average hardness will bear 9 tons per square foot, firm earth 1 to $1\frac{1}{2}$ tons, and soft earth $\frac{1}{2}$ ton or less. If a retaining wall is to be built on soft ground the site must be thoroughly drained, and a trench dug and filled with stable material, such as sand or concrete, on which the wall may be erected. In extreme cases it may be necessary to drive piles into the ground and surround their heads with concrete.

The following table gives values for the *approximate* safe stress on various soils.

TABLE F.—*Approximate safe stresses on foundations.*

Description of soil, &c.	Safe max. stress in tons per sq. foot.
Soft wet clay	0·25 to 0·33
Alluvial deposits in river beds	0·20 ,, 0·35
Diluvial clay beds of rivers	0·35 ,, 1·00
Alluvial earth and loams	0·75 ,, 1·50
Damp clay and soft chalk	1·50 ,, 2·00
Loose sand in shifting river bed	2·50 ,, 3·00
Silted sand in river bed, free from scour, and deeper than 25 feet	3·50 ,, 4·00
Hard white chalk or ordinary superficial sand beds ...	2·50 ,, 4·00
Solid clay mixed with fine sand	4·00
Sound yellow clay	4·00 ,, 6·00
Solid blue clay	5·00 ,, 8·00
Firm shale protected from the weather, and clean gravel	6·00 ,, 8·00
Compact gravel	7·00 ,, 9·00
Rock	9·00 ,, 16·00
Very hard compact rock	25·00 ,, 30·00

2. **Dimensions of retaining walls.**—The design of retaining walls is discussed in M.E., Vol. I; practical rules are also to be found in most of the engineering pocket books; those of Trautwine are as follows:—

> Wall of dressed stone or first-class rubble in mortar, thickness at base to be ·35 of entire height; good common rubble or brick in mortar ·4, and for a dry stone wall ·5.

The batter to be given to the face will depend on the type of wall and the nature of the ground, but it is usual to give the face of a dry stone wall a slope of 4 in 1 and that of a masonry wall 6 in 1, and to make their inner sides perpendicular. In dry stone walls, the base of the wall should rest on the foundation perpendicularly to the batter to be given to the face. In arranging the batter, it should be noted that the thickness at the top of a wall should not be less than 1 foot 6 inches in masonry and 2 feet in dry rubble.

Economy of material may be effected in large walls by stepping the inner face; this increases the friction and stability, but is not satisfactory in dry stone work.

3. **Surcharged walls.**—These are sometimes used in cuttings or at the foot of embankments to hold up a steep bank; the pressure brought to bear on a wall by reason of the extra height of material behind it is greater than that which would be the case with level ground and consequently a greater thickness is required.

For the design of surcharged walls *see* M.E., Vol. I.

4. **Breast walls.**—These are similar in appearance to retaining walls, but are not generally of such a substantial nature; they are used as a revetment for banks which are normally stable, but which are liable to slips owing to the material composing them being apt to assume different slopes due to variations of the angle of repose. The breast wall will arrest the slipping and prevent blockages on the road. For rough stone work it is usual to allow a large factor of safety, and construct breast walls on similar lines to retaining walls proper.

It is advisable to increase the height of breast walls above the level of the bank at the point where it meets the wall, in order that rolling stones and debris may be prevented from falling on to the road and blocking the inner gutter or side drain.

It is essential that a reasonable batter should be given to a breast wall, and that it should be well provided with weep-holes if built of masonry or brick.

5. **Strengthening of retaining walls.**—If a retaining wall shows signs of failure by bulging, it may be strengthened by tie-rods passed through the wall and attached to anchorages placed well back behind the natural slope of the ground. Another method is to step back the ground along the angle of repose, and fill in behind the wall with lighter material or with well packed rubble. If the toe of the wall shows a tendency to slip, a concrete block may be inserted in front of and below the footings.

50. *Culverts.*

1. **Box-culverts.**—Small culverts, providing up to 15 or 20 square feet of waterway, may be constructed of roughly squared stones laid dry or in cement, and spanned by a stone slab; these are sometimes spoken of as *slab drains.*

A slab drain, 3 or 4 feet in span and 5 feet in height, will serve to discharge any ordinary well defined ditch or stream not subject to abnormal flooding. A common foundation for these box-culverts is a stone pavement on which the side walls rest, as on Pl. **38,** Fig. 1A, but this is not good practice, as the walls are liable to be washed away if the paving becomes scoured out. It is better to give each wall an independent foundation with paving or invert set in cement between them, as shown on Pl. **38,** Fig. 1B, unless a more elaborate foundation, as shown in Figs. 2 and 3, is adopted. The tendency of the pavement or invert to get undermined may be diminished by sheet piling, or by the extension of the paving or invert at the entrance or exit in the form of an apron. When the fall or discharge is considerable, as on a mountain road, a catch-pit must be provided, as shown on Pl. **39**, (*see* Sec. **41**); if this is neglected there will be a danger of blockage in times of flood. Catch-pits should be one foot or more in depth, dependent on local conditions and the full width of the stream; they should be lined with stone, timber, or corrugated iron.

The thickness required for the slab to span the culvert may be calculated by treating it as a beam, provided the nature of the stone is such that an estimate of its strength can be made; useful figures for good limestone and sandstone in spans of 2, 3, and 4 feet are 10, 12, and 15 inches respectively. Slab drains may be made in two or more spans, if adequate walls are provided between adjacent spans.

The foundations of all culverts under high embankments must be made very stable, as any unequal settlement may involve fracture and produce undermining and slipping when water percolates through such fractures into the heart of the bank.

2. **Pipe-culverts.**—Pipes of vitrified stoneware, similar to those used in sewerage work, up to 2 feet in diameter, are satisfactory for small culverts, while cast-iron pipes of 4 feet in diameter have been extensively used. Pl. **40**, Fig. 1, shows a 2-foot stoneware pipe-culvert, set in concrete, and Fig. 2 a 4-foot cast-iron pipe-culvert with pitched stone aprons at either end laid on timber platforms.

The average crushing strength of stoneware sewer piping is 2,400 lbs. per square foot of horizontal section, and it has been found by experience that such pipes will quite safely stand the weight of 24 feet of earth. The principal points of importance in the construction of pipe-culverts are :—

- (i) Each end must be suitably protected and supported by a head-wall.
- (ii) Water must not be allowed to find its way to the outside of the pipe.
- (iii) The pipes must be laid with an initial camber to allow for settlement, which will be greatest under the centre of the bank; 1 inch for every 5 feet of vertical height of bank is usual.
- (iv) The joints must be well filled and caulked with cement.

Reinforced concrete pipes may be used in a similar manner, while corrugated iron pipes form a very good culvert which will remain sound for many years if galvanized; by ramming concrete round them they can be made practically permanent.

Barbed wire wound spirally round the inner core of a mould makes an excellent and cheap reinforcement for reinforced concrete pipe-culverts; the barbs keep the wire just below the surface of the finished concrete. The spiral should be stiffened with a few longitudinal pieces of wire passed in and out of the spiral to give longitudinal strength. Such pipes can be quickly made, even by unskilled native labour, with very little supervision.

3. **Arched culverts.**—When the required span exceeds 5 feet, arched culverts of stone, brick, or concrete, plain or reinforced, are usually employed. Care must be taken that these culverts do not form humps in the road detrimental to transport, especially motor transport.

The provision of properly splayed wing-walls facilitates flow on entry, reduces eddies, and promotes discharge, and the best arrangement of these is to splay them straight back from the culvert at an angle of 30° with the axis.

The arch may be semicircular or segmental; the latter has the advantage of providing a greater waterway for a given span, although it requires a thicker arch ring and produces a greater thrust on the abutments.

The thickness of wing-walls may be rather less than for retaining walls in brick or good rubble with cement mortar; the thickness should be $\frac{1}{6}$ of the height throughout, or $\frac{1}{12}$ at the top and $\frac{1}{3}$ at the base; minimum thickness at the top should be 18 inches for brick and 13 inches for rubble masonry.

Experience seems to indicate that the thrust transmitted through the arch to the abutments is more than met by the earth pressure behind them; consequently the natural deduction is that the design of abutments, in cases where high embankments are to be retained, should be examined from both aspects.

Table **H** gives typical dimensions of masonry culverts and arches from 2 to 50 feet spans; these dimensions are calculated from Trautwine's rules (*see* Sec. **49**, para. 2, and Pl. **41**).

4. **Increased efficiency of culverts.**—The efficiency of a culvert may be materially augmented by:—

(i) A curved invert, which will increase the hydraulic mean depth.
(ii) Providing approaches or wing-walls to guide the water, so that the discharge may enter without being retarded by eddies and projections.
(iii) By sloping the bed of the invert, which should be paved.
(iv) By damming up the water above the opening, so that it discharges under a head.

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. It should be noted that the segmental arch is the most economical form to use with a view to reducing the amount of embankment required to carry a road over a culvert, but it may even be found necessary to abandon the arch altogether in order to reduce the earthwork to a minimum, and to support the road on steel trough decking or reinforced concrete slabs carried by steel joists between masonry abutments. Such a design for a span of 15 feet over a stream with gently sloping banks would result in a road level about 10 feet lower than would be possible with a semicircular arch, and in an approximate saving of about 500 cubic feet of bank per foot width of roadway, besides avoiding the necessity for the use of centering.

51. *Masonry arches.*

1. **Span.**—The span to be adopted for an arch will depend upon various considerations. Large arches are more troublesome to build than small ones, and it is often preferable to erect a number of small spans instead of a single arch, provided sufficient waterway can be maintained. The size of piers will increase with the height of the roadway above the river-bed,

so that they may become of such dimensions as to necessitate an increase in span; on the other hand, a large span carrying a low roadway is uneconomical in masonry.

The nature of the stone also governs the span, in that large arch rings require large blocks of stone called voussoirs, and the quarrying of these has to be considered.

Spans of 60 and 70 feet are common, and those below 15 feet may be regarded as culverts. Regarded from the point of view of economy, the least span that should be used may be taken as being between 1·0 and 1·20 times the height from the underside of the foundations to the top of the keystone of the arch, assuming an approximate size of arch ring for the purpose of this estimation; spans greater than this ratio will reduce the cost very slightly, while those less will increase it considerably; for instance, a span 0·80 of the height will require about 15 per cent. more masonry, and one 0·60 of the height about 50 per cent. more.

2. **Rise.**—Having assumed a suitable span for an arch, the next point to be considered is the rise, that is, the height of the crown of the arch above its springing level. A semicircular arch can be built with a minimum of material, but the stresses induced in such an arch are not so favourably balanced as in one of the same span and less rise; the latter type is known as a segmental arch. The following is a comparison of the quantities in the arch ring and abutments for various ratios of rise to span, and also the relative lengths of arch ring.

TABLE G.—*Comparison of arches for various ratios of rise to span.*

Ratio.	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{5}$	$\frac{1}{6}$	$\frac{1}{8}$	$\frac{1}{10}$
Degrees in whole arc	180	$134\frac{3}{4}$	$106\frac{1}{4}$	$87\frac{1}{5}$	$73\frac{3}{4}$	$56\frac{1}{2}$	$45\frac{1}{4}$
Relative length of arch ring	1·00	·81	·74	·704	·685	·665	·655
Relative quantities for arch with two abutments	1·00	1·10	1·22	1·41	1·60	1·90	2·24

This comparison shows that a rise of $\frac{1}{3}$ to $\frac{1}{4}$ of the span is about the best all round ratio to use, as it gives an arch ring of about $\frac{8}{10}$ of the length, and the increase in total masonry quantities is about $\frac{1}{10}$ over that necessary for a semicircular arch; the stresses at the springing and crown are also better balanced.

3. **Springing-line.**—The level of the springing-line of an arch is determined by the amount of waterway required, provided navigation of the river has not to be considered; it is generally fixed by the afflux level of the highest flood.

As a rule, the springing-line is taken on one level, but occasionally, when there are land arches smaller in span than the main arches, the springing-line of such small arches is taken at a higher level, which is so much above the principal springing level as is required to bring the crown of all the arches to one level, or to one curve if the arches are of unequal height and the roadway is to be curved longitudinally.

4. **Design of arches.**—The design of masonry arches is dealt with briefly in M.E., Vol. I, and also in various civil engineering text-books.

Trautwine's rules for inelastic arches are given below, as they have been found very reliable for small spans (*see* Trautwine's Civil Engineers' Pocket Book).

(i) Radius $=\{(\frac{1}{2}\text{ span})^2+(\text{rise})^2\}\div$ twice the rise.

(ii) Depth of keystone in feet $=\dfrac{\sqrt{\text{Rad.}+\frac{1}{2}\text{ span}}}{4}+0{\cdot}2.$

For second-class work increase by $\frac{1}{8}$; for brick or fair rubble by $\frac{1}{4}$.

The proportions of abutments are obtained as follows (*see* Fig. below and Pl. 41):—

Thickness of abutment at springing level in feet

$$=ON=\frac{\text{Rad. in feet}}{5}+\frac{\text{rise in feet}}{10}+2.$$

From I lay off $IH=\frac{1}{24}$ span. Join AH. Draw GNB parallel to AH. Make GN equal to half IT. From G draw tangent GX, to mark the top of the masonry filling. Through O draw OP at batter of $\frac{3}{2}$. If P lies below the proposed base, GNB is the back of the abutment. If not, add $PR=\frac{1}{4}SQ$, draw URW parallel to AH, and draw the tangent WX. If, after this addition, QU is still less than one-half OQ (which very rarely happens), then make the base one-half the height, and draw a back line parallel to AH as before.

These additional thicknesses are to provide against earth thrusts rather than against the thrust of the arch, and would not be applied to abutment piers. In abutment piers, however, appearance affects thickness.

All abutments thus found will be safe, given good workmanship and materials, without any wing-walls and however high the embankment. If the bridge is narrow and the wing-walls close together, thus affording material support, the abutments may be made thinner. Reductions, however, should be made with caution.

This method applies equally to the smallest culvert and to the largest bridge, whatever may be the proportions of span and rise and whatever the method of filling above the arch.

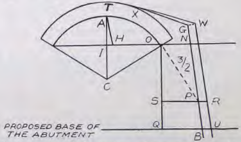

Table **H** gives typical dimensions of masonry culverts and arches (*see* Pl. **41**) from 2 to 50 feet span, calculated from Trautwine's rules.

The principal dimensions, together with axle loads, of military vehicles are given, both in tabular and diagrammatic form, in **M.E., Vol. III.**

TABLE H.—*Typical dimensions of masonry culverts and arches* (*see* Pl. **41**). Suitable for any ordinary road loads.

Rise of arch = $\frac{1}{4}$ span. External batter of abutments = 6 in 1.

		2	3	4	5	6	10	15	20	25	30	40	50
Span in feet (S)		2	3	4	5	6	10	15	20	25	30	40	50
Rise of arch ring (H)		6″	9″	1′ 0″	1′ 3″	1′ 6″	2′ 6″	3′ 9″	5′ 0″	6′ 3″	7′ 6″	10′ 0″	12′ 6″
Internal radius of arch ring (R)		1′ 3″	1′ 10″	2′ 6″	3′ 2″	3′ 9″	6′ 3″	9′ 5″	12′ 6″	15′ 7″	18′ 9″	25′ 0″	31′.3″
Thickness of arch ring in inches (t)	Best P.C. concrete, or best ashlar masonry	7	8	9	10	11	13	15	17	19	21	23	25
	Fair P.C., or second-class masonry	8	9	10	11	12	14	17	19	21	23	26	28
	Good brick or rough masonry, in cement or best lime mortar	9	9	13½	13½	13½	18	18	22½	22½	27	31½	31½
Thickness of abutment at springing (A)		1′ 6″	1′ 6″	2′ 0″	2′ 4″	2′ 8″	3′ 6″	4′ 3″	5′ 0″	5′ 9″	6′ 6″	8′ 0″	9′ 6″
Height of abutment above springing (B)		7″	9″	11″	1′ 1″	1′ 3″	1′ 10″	2′ 7″	3′ 4″	4′ 0″	4′ 9″	6′ 1″	7′ 5″
Inside height to springing (C)		2′ 0″	3′ 0″	4′ 0″	4′ 6″	5′ 0″	7′ 0″	According to local conditions					
Overall width at top (D)		4′ 10″	5′ 9″	7′ 8″	9′ 4″	10′ 11″	16′ 5″	do.	do.		do.		
Overall width at bottom (E)		5′ 8″	7′ 0″	9′ 4″	11′ 2″	13′ 0″	19′ 5″	do.	do.		do.		

The above are calculated from Trautwine's rules, the thickness of the abutments having been reduced for arches below 8-foot span, as the formula gives values in excess of current practice.

All the above dimensions are for good material and workmanship, and should be increased if either of these cannot be depended upon.

5. **Abutments and piers.**—If the masonry courses in the abutment are built normal to the back batter, as shown on Pl. **41**, Fig. 2, a stronger abutment is secured; the face stones then require to be dressed to a very slight batter in order to keep the face perpendicular. In the case of a wide roadway, it is a common practice to give abutments buttresses or counterforts to the rear. The foundations of abutments must be ample. The figures given in Table F may be taken as safe permissible stresses for foundations, and the load per foot width divided by the safe stress will give the necessary width of foundation. The permissible stress for the foundations of arch bridges should be kept low, as a very slight settlement will result in the arch being badly cracked. If the filling above the crown of the arch is more than 5 feet thick, its weight above a horizontal line 18 inches above the crown must be calculated for one foot width of roadway, and added to the load.

In dry weather and when the chances of a flood during construction are inconsiderable, hydraulic lime concrete may be used, but otherwise the foundations should be of P.C. concrete (1-3-6).

If lime mortar is used in the construction of piers and abutments, the joints should be pointed up to High Flood Level with cement mortar (1-3); before pointing, all joints should be thoroughly raked out to a depth of at least ½ inch and well washed.

In bridges of several spans, certain of the piers will be made a similar thickness to the abutments at either end of the bridge; these are called *abutment piers*. This procedure is necessary, because the normal piers are designed merely to carry the dead load of an arch and the thrust of a live load; the thrust exerted by each half-arch on a pier is balanced by a similar thrust from the adjacent half-arch, but should one arch fail, this equilibrium at once ceases to exist, and the piers will give way and cause each arch in turn to collapse. The introduction of abutment piers will arrest this destruction of the whole bridge, should one arch fail. Long arched-bridges should have abutment piers not oftener than every third span or further apart than every fifth span, and they should be placed symmetrically with the centre of the bridge, if possible.

Pls. **41** and **42** show constructional details of piers and abutments.

6. **Keystone.**—This term is applied to the centre course of voussoirs at the crown of the arch, which is the last course laid; the arch courses are laid on each side from the springing-course until they reach the keying course, when the voussoirs of the keying course are forced in to complete the arch, usually by means of heavy mallets.

The road level should never be less than 18 inches above the top of the keystone or crown of the arch.

7. **Spandrels.**—A spandrel is the triangular space between the haunches of the arch and the roadway. This space is partly filled by the *backing*, on which the *head-walls* are erected, and partly by the rubble on which the road is constructed and which the head-walls retain. In the case of large arches, the roadway is often carried on several internal *spandrel-walls* running the length of the bridge and covered by small arches or flat stones; these walls are stiffened by vertical cross-walls at intervals. It is important that none of this superstructure should be carried to any great height before the arch centres are struck, otherwise it may be disturbed when the arch settles.

The backing is of solid coursed masonry or of concrete, and its function is to prevent the arch from spreading; it must, therefore, be of sufficient height that its weight will counteract the horizontal thrust in the arch. A rough guide for the required height of backing is to carry it to a height above the springing level equal to one-third of the rise; a more reliable rule is to construct the backing up to the point at which a line drawn from the centre of the arch, and inclined to the vertical at an angle of 45°, would meet the extrados. The top surface of the backing should slope towards the head-walls, so that water percolating from the road may pass off through drainage-holes. The filling, in the spaces above the backing on which the roadway is constructed, is generally of rubble or quarry refuse.

8. **Centering for arches.**—Centres are constructed of timber, and consist of rigid ribs or frames, the upper edges of which are curved to suit the radius of the arch. They are placed from 3 to 5 feet apart, and support the voussoirs during the construction of the arch by means of *lagging* cut from 1½ or 2-inch planks.

The centres are carried on sills which are supported by uprights or trestles placed adjacent to the abutments, and intermediately if necessary. Pl. **43**, Fig. 1, shows a typical centre for a small span.

The centres rest on wooden *striking or lowering wedges*, which consist of pairs of wedge-shaped blocks of hard wood from 1 to 2 feet in length and from 6 to 12 inches wide. The wedges should have a long taper of about 1 in 10, so that by striking them out gradually the centres may be lowered by an equal amount simultaneously. Centres for large arches require to be carefully designed, as trusses and intermediate supports, such as temporary stone piers piles, or trestles, must be so constructed that no unequal settlement will take place. Pl. **43**, Fig. 2, shows a design of a large centre which has been successfully used. It is of the utmost importance that centres should be lowered very slowly, otherwise the arch will settle too rapidly and displacement of the voussoirs is likely to occur; vertical lines should be drawn on the long sides of the wedges about ⅛ inch apart, so that the centres may be lowered to the same extent at a time. The rate of lowering for a 50-foot span should be about ½ inch per day.

If an arch is rapidly built, and the keystone is in position before the cement or mortar at the voussoirs has set, the centres may be struck immediately; but when any doubt exists as to the rate of setting, the centres should not be struck for at least 28 days, and the backing should be completed before this is done.

When the centres are in position and the load comes on to them gradually from the springing towards the crown, a displacement will occur owing to elasticity, and the crown of the centre will rise up as the haunches are depressed; this causes opening of the voussoir joints at the extrados near the springing and at the intrados further up, and, whenever such openings are observed, the centres must be loaded at the crown and brought back to their normal curve. Experience in arch building will result in precautionary measures being adopted against this, by loading the centres at the crown before the commencement of the work.

CHAPTER IX.

PAVED ROADWAYS.

52. *Stone pavements.*

1. **Stone setts.**—To withstand the heaviest traffic in commercial areas, such as the neighbourhood of docks, railway sidings, and goods yards, stone sett paving provides the most durable surface. It is very noisy and quickly becomes corrugated, owing to the edges of the setts wearing under the traffic. It does not form a clean pavement, as the large number of joints hold mud and dirt, and it also produces a maximum resistance to traction; but against these disadvantages the extreme durability of sett pavements, properly laid, must be taken into account.

The setts are of igneous rock, commercially termed granite, and are dressed into blocks of various sizes, common dimensions being about 7 to 9 inches by 3 to 4 inches, and about 7 inches in depth.

It is generally considered that a concrete foundation is necessary under modern conditions of traffic. The preparation, according to the principles already laid down in Sec. **18**, of the subgrade or ground upon which the concrete is laid is the important factor in the success of such a foundation. It is estimated that good concrete, 6 inches in thickness and properly supported throughout, will withstand a load of 20 tons per square foot, and such a thickness is, therefore, sufficient to meet any kind of load that can be produced by traffic. If, however, the subgrade below is loose or capable of movement, the concrete may become unsupported and fracture will occur. Particular care must, therefore, be taken to ensure that a solid subgrade is provided, otherwise failure may take place, however excellent the concrete may be. Over bad ground, either the thickness must be increased or reinforcement introduced to provide the necessary tensile strength.

A gravel foundation may be used under stone setts in the paving of yards and depots used by horse transport, but is not recommended for heavy mechanical transport. It should be of sufficient thickness to transmit the pressure over as large an area of the subgrade as possible; 16 inches of gravel laid in 4-inch layers, each layer being separately rammed, has been found satisfactory. Setts bedded in sand, not grouted, and laid on a gravel foundation, is a common type of road paving used on the main country roads of France and Belgium, and is known as *pavé*.

In some cases setts have been laid on a hand-pitched stone foundation, similar to that described in Sec. **19**. The camber, approximately $\frac{1}{36}$ of the width of the roadway, required in the finished surface should be given to the subgrade and the foundation.

The setts are laid in a cushion of clean sand 2 inches thick spread over the foundation after it has thoroughly set. They are placed with their longer sides perpendicular to the edges of the road, and the work is commenced at the sides, each row of setts being finished at the centre with a tight fitting crown stone; the blocks must break joint in adjacent rows. The joints are filled with clean dry shingle or granite chips, small enough to pass through a $\frac{3}{4}$-inch mesh, but not so small as to pass through a $\frac{1}{4}$-inch mesh, and the setts are then well rammed to form a uniform surface with the required camber. A grouting composed of a mixture of pitch and tar in equal proportions, or of 3 parts of pitch and 1 part of creosote oil, is then poured into the joints. Care must be taken with a bituminous grout of this description to obtain a mixture which will not become too brittle in cold or run out in hot weather. In some cases a grouting of P.C. concrete is used. A layer of gravel is spread over the finished surface.

It is necessary to lay the setts diagonally at crossings, in order to prevent traffic from travelling in a direction parallel to the rows and thus forming grooves or ruts, and also to preserve as good a foothold as possible. Pl. **44**, Fig. 1, shows a section of sett paving laid as described.

It must be remembered that a pavé roadway (*see* also paras. 2, 3, and 4) is an arch, and, therefore, requires abutments; if these abutments are allowed to spread the arch fails, and the roadway breaks up. It is important, therefore, that when the edges of a pavé road become worn the abutments should be strengthened before further damage is done.

2. **Durax paving.**—The chief peculiarity in this form of paving lies in it not being laid in parallel lines, but in circular arcs springing from a longitudinal herring-bone bond, and it thus resembles mosaic work. This arrangement produces more even wear than is found in the ordinary sett paving, and provides less resistance to traction; it is, however, more slippery. The setts are cubical, and, being of smaller dimensions and covering a greater area per unit weight, are more economical than the usual setts. It is generally used on a foundation prepared similarly to that for a macadam road.

Durax paving is regarded as unsuitable for heavy traffic, but has given favourable results on secondary streets. It was originally employed to give a new surface to an old water-bound macadam road, and has proved suitable and economical for this purpose in districts where the stone is available near at hand. It has, however, been superseded by tar macadam in most cases, but might be introduced on economical grounds into military works in a similar manner to cobble-stone paving.

3. **Cobble-stone paving.**—This form of pavement is never used on roads carrying heavy traffic; it might, however, be found useful for the paving of stable yards or similar surfaces in districts where suitable stone can be economically obtained.

Round stones, from 5 to 10 inches deep and rather less in length, are embedded in a cushion of sand about 6 inches in thickness. They are set so as to break joint as much as possible, and, having been rammed until there is no further settlement, a covering of sand $\frac{1}{2}$ inch thick is spread over the surface.

4. **Brick pavements.**—Bricks are laid in the same manner as setts where suitable stone for the latter is unprocurable, the joints being grouted with pitch. They wear very unevenly and often become very slippery, and are, therefore, not recommended unless of exceptionally good quality.

53. *Asphalt paving.*

1. The bituminous materials grouped together under the term asphalt are briefly described in Appendix V. Although definitions regarding the composition of tars, pitches, bitumens, and asphalt have been drawn up and provisionally issued as British Standard Specifications, considerable controversy still prevails regarding these materials and their uses, and engineers are still experimenting with a view to the discovery of the best methods. Various views are expressed in civil engineering text-books; the nomenclature, as well as the theories laid down, will be found somewhat divergent, particularly when American practice is studied in addition to British and other European methods. Consequent on this lack of standardization, many proprietary materials and processes have been placed on the market during recent years, some bearing more or less illusive names, and each supporting its claim to superiority by means of equally convincing statistics. Many of these form excellent paving, but careful scrutiny should be exercised in arranging contracts for this class of work.

The selection of a material suited to climatic and other local conditions calls for considerable chemical knowledge in the study of the hydro-carbons, which enter into the composition of native and artificial bitumens or asphalts. Only the fundamental principles on which the formation of asphalt surfaces is based can be discussed here.

All asphalt pavings take the form of an application of a thin sheet or carpet of asphaltic material over a cement concrete foundation, laid in accordance with the principles contained in Appendix VII, which is now considered essential for such roadways, the subgrade having been prepared as described in Sec. **52,** para. 1. The camber required in the finished surface, *i.e.*, approximately $\frac{1}{18}$, should be given to the cement concrete foundation.

2. **Binder course.**—An intermediate layer of bituminous concrete, not less than $1\frac{1}{2}$ inches or greater than $2\frac{1}{2}$ inches thick, is often laid between the foundation and the wearing surface. The functions of this coat or binder course are to spread the weight of the traffic over the foundation, and to form an elastic medium which will prevent the tendency of the surface layer to crack and creep. A binder course is generally only considered necessary when an artificial bituminous concrete is used for the wearing surface instead of natural rock asphalt. This practice is common in America where the expense of the latter material is increased, owing to the fact that the usual sources of supply are in Europe.

The bituminous concrete for the binder course may be made from inferior materials to those which must be used in the wearing surface, and consists of a mixture of gravel, limestone, grit, and sand. None of these materials should be larger than $1\frac{1}{2}$-inch gauging, and an average grading for the aggregate is 30 per cent. of sand, 30 per cent. of $\frac{1}{8}$ to $\frac{1}{2}$-inch material, and 40 per cent. of $\frac{1}{2}$ to $1\frac{1}{2}$-inch gauging. When thoroughly mixed, the aggregate is first dried, and then coated with refined coal-tar pitch as in the preparation of tar macadam in bulk (*see* Sec. **24**); from 11 to 12 gallons per ton of stone are required. The pitch must be fluxed with about 12 per cent. of oil obtained from the distillation of bituminous coal, and should be tested for penetration. A sample, 2 inches in diameter and 1 inch in depth, should not show a penetration of less than 50 or greater than 70 (these measures being hundredths of a centimetre) when tested at 25° C. with a needle under 100 grammes load for 5 seconds. A " No. 2 Cambric " needle, which is 2 inches long and $\frac{1}{25}$ inch in diameter, and tapers to a point, should be used.

This prepared coating is laid on the concrete foundation at a temperature not below 80° C.; it is, therefore, advisable that its preparation should be carried out as near the site of the work as possible. The thickness at which the material is spread must allow for compression and consolidation, 30 per cent. above the final thickness being an average allowance. One ton of the mixture is required for 16 square yards at 1½ inches compressed depth.

A light roller, having a load not greater than 2,000 lbs. per foot of roller width, is used to consolidate the binder course while still warm; when the surface has cooled to the temperature of the atmosphere, a 10-ton roller may be brought on to complete the consolidation.

3. **Laying artificial asphalt.**—Climatic conditions must be carefully considered in the choice of an aggregate for the wearing surface, and the proportion of bitumen used, which may vary from 9 to 15 per cent. of the aggregate, must be arranged, either by reference to past experience or by trial, to suit local temperatures. More bitumen is required in wet climates than in dry ones. In England the proportion is usually about 12 per cent.

The artificial asphalt is made up of clean and moderately sharp sand, a *filler* of limestone dust or Portland cement, and fluxed bitumen in proportions approximating to those given in Appendix V. The bitumen used in preparing this aggregate should not have a penetration greater than 30 at 25° C., under similar conditions of testing as described in the preceding paragraph.

The wearing surface should be spread over the binder course to a thickness of 1½ inches immediately the latter has been consolidated; if an interval must necessarily elapse between the two operations, great care must be taken to ensure that the surface of the binder course, which will have been left rough, is free from dust and dirt and is perfectly dry.

The first rolling must be carried out by a very light roller of the garden type, and should not be commenced until the temperature of the surface has fallen to about 55° C.; this rolling should be continued until atmospheric temperature is reached, and until the required contour is assumed, after which a heavy roller may complete the consolidation.

Artificial asphalt is only adopted for economical considerations, as the best results are obtained from the natural rock asphalts.

4. **Laying rock asphalt.**—With natural rock asphalt the intermediate binder course, usually necessary with an artificial asphalt wearing surface, is eliminated, and only a single 2-inch layer, which can be stripped off for relaying very quickly, lies over the concrete foundation; repair work is, therefore, considerably facilitated.

The hot powdered rock asphalt, prepared as described in Appendix V, is brought to the site, special arrangements being made to keep it hot, and is quickly and evenly spread over the concrete foundation, which must be clean and dry, to a thickness of about 3 inches. Hot iron rammers, each weighing about 10 lbs., are used to commence the consolidation; the blows given are gentle at first, but increase in force as the compression proceeds. The required contour is obtained by means of specially curved and heated rammers, and the consolidation is completed by means of light hand rollers until the surface is quite cool, when a sprinkling of sharp sand is spread over it. Traffic can then be allowed on the road immediately, if desired.

Sections of asphalt paving, with and without binder course, are shown on Pl. **44.**

54. *Wood paving.*

1. Wood paving is extensively used in city streets. Detailed methods of construction are, therefore, outside the scope of this manual ; reference should be made to the latest books on wood block pavement when information is required as to its construction. The advantages and disadvantages of wood paving will be pointed out, and an outline only will be given of the general method of construction. For details of wood blocks *see* Appendix VI.

2. The advantages of wood paving over stone paving are :—

(i) It is less noisy.
(ii) It is safer for horses, if kept clean.
(iii) It is easily swept and flushed.
(iv) It affords good traction.
(v) It is easily repaired.

Its disadvantages are :—

(i) It is absorbent and unhealthy after a time : this is more pronounced in a soft wood.
(ii) It is liable to decay.
(iii) It swells when wet and becomes slippery.
(iv) It will not withstand heavy traffic for long periods.

3. Particular care must be exercised in preparing a foundation for wood blocks. The subgrade must be thoroughly consolidated to the camber required in the finished surface, and any portions of a soft or yielding nature must be removed, and hard material substituted. Proper drainage must be ensured before the foundation is laid, otherwise settlement or cracking will take place ; it has generally been found that failure of wood pavements has been due to faulty preparation of the foundation rather than to defects in the blocks. A concrete foundation is always necessary, and its thickness will depend on the nature of the subsoil and the traffic ; its surface should be brought to the required camber before it has set.

The use of a cushion of sand or pitch between the blocks and the concrete foundation has been universal until recently. With the hard woods formerly used a sand cushion was advantageous, but with the soft timber now in favour it is not considered necessary.

The prepared blocks are laid across the roadway, in a similar manner to that adopted in laying granite setts, with the shorter side in the direction of traffic. It is most important that the fibres or grain of the wood should be vertical. The joints are filled with a grouting of hot pitch. A surface grouting of sand and cement is then washed over the road and gravel spread over it. An expansion joint, to take up the expansion which will occur when the wood becomes wet, is usually formed along each side of the road between the blocks and the kerb; it is usually filled with clay or a mixture of tar and sawdust, and should not be less than 1½ inches in width. Pl. **44**, Fig. 4, shows a section of wood block pavement.

55. *Concrete roads.*

1. The term concrete road is here employed to denote a road which has a cement concrete wearing surface. Concrete roads are extensively used in America, whereas in this country they are still comparatively unknown. Detailed descriptions of the methods employed in the construction of concrete roads are outside the scope of this manual; reference should be made to the latest books on concrete roads when information is required as to their construction. The advantages and disadvantages of concrete roads will be pointed out, and an outline only will be given of the general method of construction. For details of concrete *see* Appendix VII.

2. Apart from the objections which can be made against all roads having a concrete foundation, such as the difficulty of opening up for pipe laying and repairs, the effect of frost during construction, and the necessity for closing the road for long periods while the concrete sets, a concrete road has certain other disadvantages. The chief among these are the liability of the surface to crack, non-resilience, noise caused by traffic, and the heavy initial expense. But experiments carried out in England, in view of the satisfactory results obtained in America, show that, with careful workmanship and choice of aggregate, these disadvantages can be overcome. If properly constructed, concrete roads compare very favourably with all other types, and the increased initial expenditure is more than balanced by the low maintenance charges. It must be borne in mind, however, that very careful supervision should be exercised during construction, for 90 per cent. of the failures recorded in cement concrete roads have been estimated as due to faulty construction, 8 per cent. to injudicious choice of stone, and 2 per cent. to inferior cement.

Experience is proving that cement concrete with tar spraying provides a good surface with very little dust, and that these roads will carry heavy loads if properly constructed, and especially when reinforced.

Attention may here be drawn to the fact that the design of highways could be much facilitated if mechanical transport loads could be standardized; this is very apparent when the subject of reinforced concrete roads is under consideration.

3. The importance of a good subgrade or formation on which to lay the concrete is again emphasized. Subdrainage must be carefully arranged, and the side drains must be of sufficient depth to receive any water which may collect in the formation. The nature of the subgrade will largely influence decisions as to the employment of reinforcement, for the tendency towards longitudinal cracking at the surface bears a distinct relation to the condition of the ground beneath the concrete. If an old road is being converted to a concrete one, it must be thoroughly examined and consolidated before proceeding with the new work.

The aggregate should be of maximum density, *i.e.*, the percentage of voids in the mixture must be reduced to a minimum by careful grading of the materials; consignments of materials should be carefully examined with a view to framing the proportions required for the aggregate.

It is most important that the concrete be laid in a semi-dry condition, whereby a homogeneous mass is obtained (*see* Appendix VII). Special precautions must be taken when laying in frosty weather, and, as a rule, it is very advisable not to carry out concrete work during the winter months, but to concentrate on other portions of the scheme, such as the preparation of the subgrade or the construction of footways. If traffic cannot be entirely diverted from a road during the construction, the concrete must be laid in sections on alternate half-widths. No traffic should be allowed on the new surface until after four to six weeks from its completion, during the whole of which time the concrete must be kept in a moist condition, and this period may require extension if the concrete has been laid under adverse weather conditions.

For works of any magnitude, the employment of mechanical mixers is more economical than hand-mixing.

The concrete is laid either in one or two courses. The former practice is generally accepted as being preferable, as in the two-course method there is a great danger of the bottom course becoming partially set before the upper course is laid, which results in little or no cohesion between the two.

Expansion joints are of two kinds, longitudinal and transverse. Their object is to prevent cracks in the concrete, due to its expansion and contraction under variations in temperature, by the division of the paving into suitable areas between which is interposed some elastic material.

The surface is brought to the required camber, usually about 1 in 50, by means of a heavy templet operated by men at each side of the road. It is not finished off with fine concrete. A coating of tar and granite chips is usually put on after the concrete has set and has been allowed to thoroughly dry out, in order to increase foothold and prevent abrasion and the formation of dust.

4. **Use of reinforcement.**—The introduction of reinforcement has been found preferable to an increase in thickness under the following conditions :—

(i) Unstable subgrade.
(ii) Very heavy traffic.
(iii) Abrupt changes of gradient.
(iv) Widths greater than 25 feet.

Reinforcement is intended to take tensile stress only and to prevent cracks; in normal conditions it is laid from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches from the bottom of the concrete. When very soft or made ground is being dealt with, additional reinforcement may be placed near the top of the concrete, as on such ground the road will be required to act as a raft, and both its upper and lower surfaces will tend to be in tension and compression alternately when a heavy load moves along it. Reinforcement should be laid in a perfectly clean condition; if coated with oil or rust, it will not bond effectively with the concrete.

Transverse joints are often dispensed with in reinforced work; if they are insisted on, the reinforcement should not cross them. When the road is laid in two halves longitudinally, no reinforcement should project along the central joint, and the two halves should be kept independent of each other; the joint between them is filled with felt, pitch, or some other elastic material.

Pl. **45** shows a reinforced concrete road under construction.

56. *Footways, kerbs, and gullies.*

1. **Footways.**—The width of a footway depends on the estimated amount of pedestrian traffic; a common size is about one-fifth of the total width of the roadway between its boundaries. They should be given a cross-fall to the gutters of from $\frac{1}{8}$ to $\frac{1}{2}$ inch per foot, according to the nature of the material used. The foundation for footways must be substantial and well consolidated; broken brick, clinker, or gravel is the usual material.

Gravel footways are commonly provided when foot traffic is light and occasional. The material is laid to a thickness of 3 or 4 inches and rolled with a light roller.

Tar paving forms a good footway; it is laid in two courses. The lower course is formed of material, of $1\frac{1}{2}$ to 1-inch gauging, similar to that used in tar macadam roads (*see* Sec. **24**), and is consolidated to a thickness of about 2 inches. A course of finer material or tarred chippings is rolled in over this, and the surface is sprinkled with sand.

Rock asphalt or *mastic asphalt* forms a good footway when laid on a concrete foundation.

Slabs or *flagstones* of suitable stone (Millstone grit or Yorkshire stone) are very commonly used, and form one of the best footways where traffic is likely to be congested. They are usually $2\frac{1}{2}$ or 3 inches thick, and are carefully and evenly set in mortar on a 4 to 6-inch gravel, clinker, or broken brick foundation; the joints should be grouted with cement and sand. There are numerous artificial flagstones on the market which make satisfactory pavements, and these are laid in a similar manner to stone paving slabs.

Cement concrete footways are also common. The principal points emphasized in the preceding section apply equally in the mixing and laying, but the concrete is generally laid in two courses, a base course of about 3 inches being covered by a wearing course of 1 inch of finer material. Light reinforcement may be employed, in which case the paving should be continuous, but otherwise it should be completely jointed through both courses at intervals of from 6 to 8 feet. The surface must never be finished off too smoothly, or it will become inconveniently slippery.

Bricks and *tiles* may be used, but generally form an uneven surface due to their unequal settlement; they are not recommended, unless they can be so readily obtained that their use will effect considerable economy. Only the best vitrified bricks should be employed, and these will be found slippery in wet weather.

2. **Kerbs and gutters.**—Kerbs may be of stone, concrete, or iron; the last named are not often used owing to expense. Kerbs should be of such a height that, while they prevent vehicles from encroaching on the

footways and water from overflowing from the gutters, they do not inconvenience pedestrians. The height can vary from 3 to 10 inches, but 6 to 8 inches is most suitable. Kerbs are laid in a base of broken stone, gravel, or concrete, which, when deep and heavy kerbing is used, must be carefully laid and rammed into position on a consolidated bed. In paved roadways the kerbs and gutters are usually laid first, and the road made to conform with them. Types of kerbs and gutters are shown on Pl. **46**.

The dimensions of stone kerbs vary between 4 and 12 inches in width and 9 to 24 inches in depth, according to the class of road and the nature of the traffic; they are laid in lengths of from 3 to 6 feet. The stone used is generally hard granite, syenite, or basalt. The exposed faces and ends are dressed, the front face being splayed. The joint between adjacent lengths of kerbing should not exceed $\frac{1}{8}$ inch in width.

Concrete kerbs are either made in moulds or laid *in situ*. They are generally 6 inches thick, 18 to 24 inches deep, and 8 to 10 feet long; they are very suitable for roads with light traffic, but are not recommended for main streets. Pl. **46**, Fig. 3, shows a concrete kerb and gutter made in one piece. Where a concrete kerb and a concrete footway are being laid simultaneously, a longitudinal expansion joint should be made between the two.

Gutters or channels are necessary along the edges of paved roadways to carry the surface water to the gullies or drains. Where there is a danger of scour on country roads, cobblestone gutters are provided, but in street-works they are usually of setts laid longitudinally, stone or concrete slabs, or bricks. They should not be laid with a flatter gradient than 1 in 150, and should have a slightly greater cross-fall than the road itself. It is sometimes preferable to give them a concave surface, making the depth of the gutter about $\frac{1}{8}$ of its breadth.

3. **Gullies.**—Where surface water is discharged into sewers, gullies are placed at intervals along the side of the roadway to receive the water from the gutters. The interval between them will depend on the size of gully used, the camber of the road, and the gradient.

Gullies are usually made of cast-iron or earthenware, and each fulfils the functions of a small catch-pit. The mud and silt washed down is collected in a small chamber, which is periodically emptied by means of scoops; the water overflows through an outlet pipe near the top of the gully; rubbish, such as paper and leaves, is prevented from choking the pipe by means of an iron grating resting over the top of the gully flush with the gutter. Where heavy traffic is to use the road, care must be taken to ensure that the outlet pipes of gullies are sufficiently protected.

Gullies should be of sufficient capacity to cope with the maximum rainfall, and the bars of the gratings should not be so close as to impede the flow of water or to become choked, otherwise flooding will occur. Provision must be made by traps in each gully to prevent sewer gas from escaping. On steep gradients, or where a large flow of water has to be dealt with, the size of gullies becomes too great for them to be conveniently made and handled in one piece; brick or concrete chambers are then constructed on the same principle and lined with cement.

APPENDICES.

APPENDIX I.

Stone.

1. **Selection of stone.**—The study of the rocks forming the earth's surface is a science in itself. It is impossible to describe in detail here the numerous different varieties of stone useful in road construction; but it is important for the engineer to be acquainted with the derivation and qualities of those commonly in use in civilized countries, and also to have a knowledge of the properties and constituents which combine to form a good road-metal, since in an undeveloped country he will have to use his own judgement in selecting suitable material from the rocks locally available. A brief reference is, therefore, made below to the groups of rock generally useful, and to the means of testing them; for further information the study of the following works is recommended:—

Geology for Engineers—
Lt.-Col. R. F. Sorsbie, R.E. (C. Griffin & Co.)
Text Book of Petrology—Igneous Rocks.
Hatch. (C. Allen & Co.)
Text Book of Petrology—Sedimentary Rocks.
Hatch & Rastall. (Griffin & Co.)
Applied Geology—
Elsden. (Quarry Publishing Co.)

The qualities to be desired in a good road-metal are:—

(i) Hardness, combined with toughness.
(ii) Durability, *i.e.*, power of resisting chemical action when incorporated in a road surface.
(iii) Binding properties.
(iv) Maintenance of a rough surface under friction; this particularly refers to stone setts.

The value of a rock for road-metal depends, as a rule, on the amount of silica present, as this mineral, above all others, contributes towards its toughness and durability, but a very hard and sharp stone, such as flint, is injurious both to horses' feet and to tyres.

It should be borne in mind that a great deal depends on the manner in which the stone is broken, for the best stone badly quarried may give inferior results to a softer local variety which has been carefully handled. The harder the stone the smaller should be the gauging of the road-metal.

When selecting a stone for road-metal, first consideration must be given to the type of road required, the traffic to be dealt with, and the gradients anticipated.

It is in most cases both expedient and economical to use locally obtained stone in the construction of military roads, provided such is not wholly unsuitable, but, in view of the extra cost of maintenance consequent on using an inferior material, it is often, for permanent roads, more economical to incur a larger initial expense by the use of the best road-metal.

2. **Main classification of rocks.**—Rocks are divided into two main groups, known as igneous and sedimentary.

The *igneous rocks* are of volcanic origin, and their presence is due to the earth's internal heat, which, during different geological periods, has caused large quantities of molten material to be forced to the surface, where cooling has taken place at varying rates. They yield the best road-metal, the process of cooling from intense heat producing a harder and more coherent material than is found among the sedimentary rocks.

The *sedimentary rocks* have been formed by the deposit from time to time on the earth's surface of various sediments, often themselves of igneous origin, which have reached various stages of consolidation through age, pressure, and chemical action. The nature and amount of these changes determines their value as a road-metal.

3. **Igneous rocks.**—Geologically, the igneous rocks are classified according to the amount of silica they contain, those having more than 66 per cent. being called *acid* rocks, and those with less than 66 per cent. being called *basic.* Commercially, the principal rocks used in road construction are known as *granites* which include syenites, felsites, diorites, and other varieties, and *basalts* which include whinstones, diabases, dolerites, traps, &c.

It should be borne in mind that the nature of a rock cannot be accurately determined from its trade name, as it is the custom of quarry owners to use the geological names of the best rocks to which their products approximate; thus there are many so-called granites which are not in reality true granites, and similarly with basalts. It is, therefore, advisable to make a careful examination of specimens, unless a previous reputation has been established.

Granites.—True granite is a hard crystalline rock which has cooled comparatively slowly from the molten state, and generally at considerable depth below the surface, resulting in the formation of well-defined crystals of quartz, felspar, and mica.

Granites vary considerably in texture according to locality, some being coarsely grained with large crystals (as in Shap, Scotland, Mount Sorrel, and Cornwall), while others (as in Guernsey) are very close grained; the latter are preferable for road-metal.

Quartz porphyries are rocks of similar composition to true granite, but which have cooled too quickly for complete crystallisation; certain of the minerals have crystallised before the others, with the result that the rock is composed of large crystals surrounded by fine material, producing what is known as *porphyritic structure*; the large crystals are called *phenocrysts*, and are usually of quartz or felspar. The Cornish elvans are typical of this class of igneous rock, and are extensively used as road-metal. The quartz felsites of Cumberland are similar rocks.

Syenites and *diorites* are varieties of igneous rock approximating to true granite but with distinct mineralogical differences, the chief of which is the absence of quartz; in most cases they are closer grained, and their exact composition, and, therefore, quality, can only be determined by means of the microscope. They are found in North Wales, Leicestershire, and the Channel Isles, all of which localities yield excellent road material.

Basalts, diabases, and *whinstones* are igneous rocks which have cooled at or near the surface, and consequently at a much more rapid rate than in the case of granite and its allied rocks; their texture is, therefore, much finer and more closely grained. They are *basic* rocks, heavier than granite, and make a very good road-metal, being extremely tough and preserving a rough surface. They are found in Scotland, North Wales (Penmaenmawr and Pwllheli), Shropshire, Northumberland (Whin Sill), Antrim, and North Yorkshire (Cleveland Dyke). Imported Rhenish basalt is also an excellent material.

4. Sedimentary rocks.—The sedimentary rocks do not furnish a road-metal of such a high quality as the igneous rocks, but, nevertheless, they are extensively used in localities where the latter are not easily procurable. The chief among them are *sandstones, limestones*, and *flints*. They are widely distributed and of very varying quality, according to the amount and nature of the silica contained in them.

Sandstones are rocks which consist of grains of quartz cemented together in the process of sedimentation; it is the nature of this cement which determines their value commercially. The size and shape of the quartz grains depend upon the manner of deposit and also influence the quality of a sandstone. Wind-blown sand always consists of rounded grains, while that formed entirely by the action of water will be found to possess sharp and angular grains which are better as a constituent of sandstone. A specimen of sandstone can readily be judged in this respect by means of an ordinary pocket lens.

The best sandstones, called *quartzites*, are those with angular grains of quartz cemented together by deposited silica, the whole forming a compact mass of quartz; these form very durable road-metals. A sandstone having a calcareous or lime cement is of inferior quality. A sandstone having coarse angular grains is called a *grit*.

Sandstone is quarried as *freestone* from beds of thick deposits, and as *flagstone* from thin beds. Sandstone occurs in various localities in Great Britain, and is used as road-metal under its local name; the following are some of the more well known varieties; Greywethers, Lickey Hills, Quartzite, Hampden Stone, Hastings "granite," Yorkshire flags, Gannister and Millstone Grit.

Limestone is a sedimentary rock of organic origin, *i.e.*, it is formed by the deposit of minute shells and fossil remains of organisms in the form of soft mud, which has subsequently become compact and crystalline. It consists principally of calcium carbonate, sometimes to the extent of 98 per cent. This calcium carbonate, or carbonate of lime, has two crystalline forms known as calcite and aragonite, and these form the matrix in which the organic fragments are cemented together.

Aragonite is less stable and more soluble than calcite, and, therefore, the carbonate of lime, originally present as aragonite, is generally dissolved and re-deposited as calcite in the matrix. Another change may occur in the calcite, namely, the replacement of half the lime by magnesia, giving a double carbonate of lime and magnesia as a matrix; this is much harder and less soluble than calcite, and such a limestone is known as a *dolomite*, and forms a very good road material.

The best limestone for road-work, however, is one in which the carbonate of lime forming the cementing material has undergone still further changes, resulting in replacement by silica ; these changes sometimes extend to the fossil fragments as well as to the matrix, the whole rock being altered. The *Portland limestone* is an example of this.

It will be seen that the value of a limestone as a road-metal can only be accurately estimated by a microscopic study of these conditions. Limestone in various forms is very widely distributed, and is used as a road-metal where better stone cannot be obtained. It makes a dusty road in dry weather and a very muddy one in wet weather, and its wearing qualities are greatly inferior to those of the igneous rocks.

Flint consists almost entirely of pure silica, and is found in the form of nodules of varying sizes occurring in the chalk beds. The importance of silica as a constituent of the rocks used in road making has already been referred to, but, in spite of its high percentage of this mineral, flint does not furnish such a good road-metal as the igneous rocks with less silica, owing to its extreme brittleness. Flint contains water which it loses after exposure to the weather. The presence of this water contributes largely towards the brittleness of the stone, and it is, therefore, important that newly-quarried flints should not be used in road making ; those picked from the surface of the chalk are preferable, being tougher and more durable.

Chert is a variety of flint found in some limestones, and its origin is analogous to the replacement of carbonate of lime by silica, referred to in the remarks on limestone. It is preferable for road-work to the chalk flint, as, although its silica is not so pure, it does not possess the extreme brittleness of the true flints.

5. **Gravels** are accumulations of stones and sands formed by the denudation and disintegration of the older rock formations. The stones may be angular and sharp, or rounded in the form of pebbles ; the former are preferable. Screening is generally necessary, and stones over 1 inch in diameter must be broken. The binding power of gravel depends on the nature of the finer particles, and these should be of sand rather than of clay.

Shingle is a type of gravel having rounded pebbles ; it is of little value as a road material, but is extensively used in concrete.

6. **Artificial stones.**—Artificial stone is much used as a paving for footways. It is made by mixing carefully chosen clean chippings from the best rocks, such as granites, syenites, or good hard gravel, with Portland cement, and is cast in moulds to the required size and thickness either as blocks or as flagstones. There are many varieties, usually made by quarry owners in localities where suitable rock is being quarried.

Blast furnace slag from iron foundries is another type of artificial stone which forms a good substitute for natural road-metal in districts where it can be easily obtained. It consists of fused silicates, and closely resembles the finer-grained igneous rocks although it is rather more brittle, having cooled at a faster rate. It does not bind well, but absorbs tar and is more durable than limestone, though making an equally muddy surface in wet weather. It is a good material for tar macadam.

7. **Road-metal in India.**—*Kunkur* is largely employed in India as a road-metal, especially in the United Provinces. It is a limestone conglomerate and very tough; its structure is compact and often nodular. It is usual to stack kunkur for repair work along the roadside, and to leave it there for one year, so that all earthy matter may be washed out by rain, and that it may harden by exposure.

Overburnt or clinker brick, which makes very good roads but does not provide a very lasting surface, is used in Bengal where kunkur is not universally obtainable.

Moorum, a kind of decayed igneous rock, is most commonly employed in Bombay where, however, igneous rocks are usually imported for use on the large trunk roads and streets. It has the appearance of a gravelly sandstone of reddish-brown colour, and is readily quarried with a pick and easily broken. 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 igneous rocks, and requires more care and attention; no sand or binding is necessary in laying or rolling, and the roller used should not be more than 10 or less than 4 tons in weight.

Laterite is used in Madras, Burma, and the East Coast of India on country roads for light traffic. It is a reddish rock consisting of silicate of alumina and oxide of iron, and is believed to be a gneiss altered in form by atmospheric agency extending over a long period. It hardens on exposure to air and water, being quite soft when dug out. It makes good smooth roads but is not durable.

8. **Tests.**—The most reliable test of a stone used for road making is that of experience in its actual wear by observation: such information as has been obtained by this means is limited to the varieties of stone in use in civilized countries, and other tests must be applied to the materials met with in undeveloped countries.

The chief of these tests are:—

(i) Attrition test, for hardness and toughness.

(ii) Absorption test, which gives the increase in weight after immersion in water for a definite period. The tendency to disintegrate after frost can be thus established.

(iii) Percussion test, which serves as a guide in estimating the amount of wear which will take place through the impact of horses' feet and tyres.

(iv) Specific gravity. This is useful when estimating the amount of stone by weight required for works.

For details of these tests *see* "Modern Road Construction," Francis Wood (C. Griffin & Co., Ltd.).

APPENDIX II.

Quarrying.

1. In military engineering, the necessity for quarrying will arise in cases where it becomes essential to supplement the supply of stone by opening up or requisitioning and working existing quarries in or near the

area of operations, or where large works have to be carried out in districts rich in suitable local stone (Sec. 3). A knowledge of the methods employed is therefore necessary, in order that local resources may be exploited whenever desirable. The study of all types of modern mechanical rock-drilling apparatus, air compressors, and stone crushers is beyond the scope of this work, but details of these will be found in M.E., Vols. IV and VIII.

2. **Selection of site.**—The choice of a convenient site will be the first consideration in opening up a new quarry, and the determining factors in this are the facilities for approach both by road and by rail, the amount of *overburden* to be removed, and the *bedding* of the rock ; of these, the second is the most important.

Road and rail facilities will usually be developed as the quarrying proceeds and the output increases, but a site near a good main road should be chosen at the commencement, so that as little work on approach roads as possible need be done. At the same time, convenient railways must not be overlooked. It may be necessary in some countries to choose the sites of quarries along the line of a proposed new road, and to commence working them as a preliminary ; such quarries should be numerous and small, and their location will not present the difficulties attending a larger undertaking.

3. **Preparation of site.**—In some cases the rock itself forms the surface, while in others there is a considerable depth of earth to be removed before the level of the rock is reached : this is called *overburden*, and the process of removing it is called *stripping*. Since all labour employed in stripping must be regarded as yielding no immediate return, it follows that the depth of overburden to be removed before any rock can be quarried must be of primary importance in the choice of site from the point of view of economy in labour. The overburden must be removed for a sufficient distance from the face before blasting to ensure that none of it will fall into the quarry after the explosion, as this will entail waste of labour in separating the useless material from the stone. The area to be stripped will depend on the amount of stone required, and in calculating this a useful average figure is to allow 13 cubic feet for each ton of rock removed. It is important that all earth removed should be dumped in such a position as not to interfere with the subsequent working of the quarry.

The thicker layers of stratified rocks are called *beds*. These may rest one upon the other horizontally but are generally inclined to the horizon, the angle of inclination being called the *dip*. The rock should dip towards the face chosen as that on which to work a quarry. This will considerably facilitate the removal of stone, and will also result in the floor of the quarry sloping down from the face, thereby promoting drainage by gravitation and also a down gradient for loaded trolleys.

4. **Hand drilling**, as a rule, will only be resorted to in small quarries where it is not considered expedient to introduce power installations for the working of mechanical drills. It is dealt with in detail in M.E., Vol. IV.

5. **Machine drilling.**—The quickest and most economical method of obtaining the rock in large quantities is by means of mechanical drills, the motive power being usually compressed air, though steam may sometimes be used. In the case of small quarries situated at some distance apart, a mobile steam engine may be employed to supply the power for

drilling, and be taken to each quarry in turn. Steam tractors have been successfully utilized in this capacity. In large quarries of a permanent type, however, an air compressor plant with a central power house is the more economical method of working. Details of air compressor plants will be found in M.E., Vol. VIII.

Percussion drills consist of the following essential parts :—A cylinder in which a piston moves backwards and forwards under the pressure of compressed air or steam admitted through valves, a piston rod to the forward end of which is attached the cutting tool or drill-bit, and some arrangement by which the drill-bit is partially rotated between each stroke.

The amount of work which can be accomplished by a mechanical drill depends on the nature of the rock, the condition of the cutting edge of the drill, and the size of the hole. In hard igneous rock, with a good drill, a 2½-inch hole can be bored at the rate of 4 inches per minute, and a depth of 5 feet may be reached in an hour, including the time taken for changing drills and clearing out sludge from the hole.

Well-known types of rock drills on the market are those of the Ingersoll-Rand Company The *Ingersoll-Sergeant drill* has been successfully used in various theatres of war in working large quarries for road stone. The "*Butterfly*" *jackhammer drill* and the *Temple-Ingersoll Electric Air drill* have also been used in military work, the latter being a useful type where electric power is available. These drills are briefly described in M.E., Vol. IV.

6. **Blasting.**—The properties and uses of explosives, and the differences between the action of high and low explosives are fully dealt with in M.E., Vol. IV. These differences are nowhere more strikingly illustrated than in the application of explosives as blasting agents for quarry use. If large blocks of stone are required for masonry work, the use of a low explosive with a comparatively slow action is necessary ; on the other hand a high explosive, producing shattering effect, is preferable in quarrying for road-metal, as the subsequent sledging required is thereby reduced to a minimum. It must not be overlooked that bore-holes are often wet, and waterproof cartridges must be provided when the explosive used is one to which moisture is detrimental.

APPENDIX III.

Stone breaking.

1. **Gauging.**—Before the stone obtained from a quarry can be utilized in road-work, it must be broken to the necessary size for laying, which varies according to the nature of the rock and the traffic anticipated. For the foundation or soling, large stones of from 8 to 12-inch gauging are required : rounded stones are not so good as those which approach more to the pyramid in shape. For the surface of a macadam road, with a stone of moderate hardness, the metalling should be applied in stones which will pass through rings of 2½ and 2 inches in diameter, that is of 2½-inch and 2-inch gauging, but for tougher stone these figures may be reduced to 2¼ and 1¾ inches, where the heaviest traffic has to be carried ; for mountain roads the gauge depends upon the gradient, a smaller

gauge than $2\frac{1}{4}$-inch being usual. The stones should be of uniform size, and of as nearly cubical shape as possible, to ensure even wearing: stones of unequal size and irregular shape will not bind well, and form an uneven surface with very short life.

2. **Sledging.**—The boulders from the quarry face require to be broken to a convenient size before they can be dealt with either by hand or by mechanical breakers. This is usually done by means of sledgehammers, except in the case of large boulders of the hardest rock, when small explosive charges may have to be used. A convenient size for handling is 16 inches by 9 inches, and the average daily amount of a moderately hard rock which one man, working nine hours a day, can sledge is 18 tons.

3. **Handbreaking.**—Handbroken stone is considered by many engineers preferable to that broken by mechanical means, but the cost of labour to produce it in large quantities is prohibitive, and stone-breaking machines are now in general use in all large quarries. The advantage of handbroken stone is its uniformity in size and shape; machine-broken stone is apt to be rounded and cracked. A good stone-breaker will produce about 3 cubic yards of metal per day from flint or limestone, about 2 cubic yards from whinstone, and from $\frac{3}{4}$ to $\frac{1}{2}$ cubic yard from the harder gneous rocks.

4. **Stone-breaking plant.**—The location of a stone-breaking plant in a quarry must be carefully considered, in order that the greatest possible advantage may be taken of gravitation. The essential parts of such a plant, in addition to the power installations, are the charging platform, the stone-breakers, the screens, and the bunkers; these must be arranged so as to avoid all unnecessary labour against gravity. If the charging platform and breakers cannot be so placed that the stone will fall from the breakers to the screens, elevators must be used. The stone should fall from the bunkers by its own weight, and sufficient space must be allowed beneath the bunkers to enable trucks or lorries to be run in for loading. The feeding may either be by hand or by direct tipping; the former is preferable, as it affords opportunity for better supervision and the selection of the material coming from the quarry. Pl. **47** shows a typical arrangement of breaking plant at a quarry.

There are three types of stone-breaking machines in general use, viz., jaw-crushers, gyratory breakers, and roller breakers.

Jaw-crushers.—Baxter's stone-breaker on this principle has been used in military work. Messrs. Hadfields, Ltd., have several forms on the market.

Gyratory crushers.—The "Heclon" gyratory breaker supplied by Messrs. Hadfields, Ltd., is an example of this type.

Roller crushers.—Messrs. Hadfields, Ltd., supply a roller crusher with toothed rollers.

5. **Screening.**—The broken stone from the crushing machines is screened by being shot into revolving cylindrical steel screens perforated with holes of various sizes which sort the metal accordingly. In large quarries several screens are used, and placed over the bunkers, shoots being arranged so that material of a given size always finds its way into the same bunkers. The rejected material is usually carried back to the

level of the charging platform by means of bucket elevators for re-crushing.

A very useful type of mobile plant for small quarries, which can be both drawn and operated by an 8 h.p. tractor or steam roller, is shown on Pl. **48.** AA are the fly-wheels of the crusher, and the driving shaft carries two pulleys for driving the top and bottom screens, B and C, which are operated by bevel gearing. The stone, having been crushed, is shot into the lower screen C, where the finer material is got rid of; the elevating belt D, carrying buckets, and revolving with the screens, then raises it to the upper screen B, perforated with holes of the required gauging, through which the macadam passes into a delivery shoot.

APPENDIX IV.

Tar.

1. The waste products formed in the manufacture of coal gas provide the most common source of supply of crude tar, the composition of which is variable and can only be accurately determined by close chemical study. It consists of light and heavy oils, ammonia liquor, and pitch—the last named being the valuable constituent from the point of view of the road engineer.

Before the crude tar can be used, it must be treated to remove the useless ingredients by boiling or distillation, by which means the lighter oils and ammonia liquor are driven off, leaving a residue of pitch. The usefulness of tar depends on the degree to which this refining is carried. Heating to too high a temperature will produce a pitch which quickly becomes brittle, and lacks the necessary adhesive properties by which its value is determined: on the other hand, if the temperature has been insufficient to drive off the lighter oils and ammonia liquor, these will ultimately cause disintegration, and the residue is equally useless. Tar is always applied hot; it should draw out in thread-like filaments when cool; the lighter the tar the longer should it be boiled, but care must be taken that overboiling is avoided. A common type of tar boiler is shown on Pl. **15,** Fig. 2.

2. Tar is used in road construction as a binding agent, and in conjunction with granite or hard stone chippings as a wearing surface for an existing road. In the former case it is poured in during consolidation, or applied to the broken stone or slag before laying, thorough mixing producing a bituminous concrete known as tar macadam. As a wearing surface it is applied to the surface of metalled roads by tar spraying machines or by hand; in this case it acts also as a dust preventive. Pitch from coal-tar is also used as a grouting in wood pavements.

It must be borne in mind that the specifications given below are for work which is to be carried out in temperate climates. The melting point of tars indicates their relative hardness and brittleness, and this must be examined before a suitable tar for use in tropical countries can be decided on. Native bitumens, such as that from Trinidad, are much more stable, and, therefore, preferable to tar for roads which are to be subjected to considerable ranges in temperature.

3. The following is an extract from the British Standard Specification for tar to be used in **tar macadam** :—

The tar should be derived wholly from the carbonisation of coal, except that it may contain not more than 25 per cent. (by volume) of tar produced from the manufacture of carburetted water gas.

Its specific gravity at 15° C. should not be lower than 1·19 or higher than 1·24. On distillation in a litre fractionating flask, one-half to two-thirds filled, it should yield the proportions by weight of distillate given below, the temperature being read on a thermometer of which the bulb is opposite the side tube of the flask :—

Below 170° not more than 1 per cent.

Between 170° and 270° C. not less than 12 per cent. or more than 18 per cent.

Between 270° and 300° C. not less than 6 per cent. or more than 10 per cent.

Total distillate between 170° and 300° C. should not be less than 21 per cent. or more than 26 per cent.

4. **Pitch suitable for pitch grouting.**—Pitch of the required consistency is obtained most conveniently by running it off from tar stills in which the distillation of the tar has been stopped at the point at which the residual pitch will give a penetration of 70 (or such other penetration as may be specified to suit climatic or local conditions) when tested at 25° C. with a penetrometer (*see* Appendix V). Harder pitch may be softened or *cut back* in the still or in a mixer at the tar works, to the extent necessary for it to give this penetration by the addition of tar oil. Where pitch of the required consistency cannot be thus directly procured, it may be prepared by softening *commercial soft pitch* with *tar oil* until the required penetration is obtained.

Commercial soft pitch.—The pitch should be derived wholly from tar produced in the carbonisation of coal, except that it may contain not more than 25 per cent. of tar produced in the manufacture of carburetted water gas.

On distillation in a litre fractionating flask, one-half to two-thirds filled, the pitch should yield the proportion by weight of distillates stated below :—

Below 270° C. not more than 1 per cent.

Between 270° and 315° C. not less than 2 per cent. or more than 5 per cent.

The pitch should contain not less than 18 per cent. or more than 31 per cent. by weight of free carbon ; the free carbon should be determined by the weight of the residue after complete extraction of all matter soluble in benzol or carbon bisulphide.

Tar oil.—The tar oil should be a filtered green or anthracene oil, and should be derived wholly from similar sources as the commercial soft pitch above described. Its specific gravity at 20° C. should be between 1·065 and 1·085. It should remain clear and free from solids after standing for half an hour at 20° C.

Distilled under similar conditions to those above described, it should yield the following proportions by weight of distillate :—

Below 170° C. not more than 1 per cent.

Below 270° C. not more than 30 per cent.

Below 330° C. not less than 95 per cent.

5. **Tar suitable for tar spraying.**—The tar used should be of the following specification. It must be coal-tar, and if pitch be added the latter must be of the same origin. The specific gravity at 15° C. must not be lower than 1·16 or higher than 1·22. It must be free from water, acids, and naphthalene, and should not yield a distillate below 170° C. Up to 270° C. there should not be more than 26 per cent. or less than 16 per cent. of distillate, which should remain clear and free from solids when maintained at a temperature of 30° C. for half an hour. Between 270° and 300° C. it should not yield a distillate of less than 3 per cent. or more than 10 per cent. The amount of free carbon should not exceed 20 per cent. or be less than 12 per cent.

The pollution of rivers and streams may be guarded against by using a tar of not lower specific gravity at 15° C. than 1·18 and which does not contain more than 1 per cent. of water or gas liquor, the ammonia in which is equal to not more than 5 grains per gallon of tar. It should not contain more than 1 per cent. of light oils or more than 3 per cent. by volume of crude tar acids.

APPENDIX V.

Asphalt.

1. **Artificial asphalt.**—If a suitable stone is crushed into small fragments, and incorporated with the correct proportions of sand and pitch or bitumen in a molten state, a bituminous concrete will be formed which furnishes an excellent road surface on setting; such a material is termed *asphalt*. The pitch obtained from coal-tar may be used, but is inferior to certain natural bitumens which are found in different localities, and the latter are in general use for this kind of work. The most important bitumen deposits are the pitch lakes of Trinidad and Bermudez (Venezuela), and the land deposits of Cuba, Mexico, Peru, and Mesopotamia.

2. **Natural bitumen** is insoluble in water but soluble in carbon bisulphide. The following test is usually applied in cases where a specification for work stipulates the use of Trinidad or other native bitumen, and it is suspected that coal-tar pitch is being substituted. Dissolve a little of the substance in carbon bisulphide and filter off the resulting liquid; evaporate the filtrate to dryness, and heat the residue until it can be ground into a fine powder; take about $\frac{1}{10}$ gramme of this powder and treat it for 24 hours with 5 c.c. of strong fuming sulphuric acid, and then add about twice the volume of water and thoroughly stir. If coal-tar pitch has been substituted the resulting liquid will be of a dark brown or black colour, but natural bitumen will produce a light yellow liquid.

3. **Refined bitumen.**—Crude native bitumen contains water and various mineral impurities, which are removed by heating to a temperature of 160° to 180° C. for a period of 8 to 10 hours, leaving a residue known as refined bitumen. This contains two ingredients, one a yellow oil called petrolene, and the other a hard black brittle substance known as asphaltene, and these two constituents are not always present in the same proportion. An excess of petrolene produces a low melting point and a lack of stiffness,

while too much asphaltene renders the bitumen brittle. Refined bitumen is generally too brittle and, before it can be used, requires to be mixed with a mineral oil obtained from the distillation of petroleum at a temperature of about 170° C., to give it the necessary viscosity. This process is called *fluxing*.

The viscosity of the bitumen determines the behaviour of the road surface under variations of temperature and traffic, and is, therefore, very important. Refined bitumen is tested for its viscosity by means of an instrument called a *penetrometer*, by which the penetration of a weighted needle, placed in contact with a specimen for a given time and at a known temperature, is measured. A bitumen is described as having a penetration of 64 when a needle 2 inches long and 0·04 inch in diameter, weighted with 100 grammes, will penetrate a distance of 6·4 mm. in 5 seconds at a temperature of 25° C.

4. **Bituminous concrete** is formed by mixing the refined bitumen mixture, described in para. 3, with sand and calcium carbonate in proportions which vary according to the source of supply of the bitumen. The following are figures for Trinidad Lake bitumen :—

	Per cent.
Refined bitumen	12–15
Sand	83–70
Calcium carbonate	5–15

It is important that the bitumen mixture should be free from all impurities, and should be viscous at ordinary temperatures when it should be capable of being drawn out into fine threads.

5. **Rock asphalts.**—There are also large deposits of rock, usually limestones, which themselves contain natural bitumen in such quantities that they may be softened by heating, and will consolidate again on cooling ; these rocks are termed rock asphalts or bituminous rocks, and from them is obtained the material used in the formation of the best asphalt surfaces. The principal sources of supply are Val de Travers (Switzerland), Limmer and Vorwohle (Germany), Maestu (Spain—a bituminous sandstone), Seyssel (France), and Ragusa (Sicily).

The artificial asphalt already described is produced by the incorporation of refined bitumen with various rock substances, the bitumen forming the cementing matrix which binds the ingredients together. In the rock asphalts this result has already been arrived at by natural processes, and the rock is a natural bituminous concrete containing lime, sand, and other minerals, together with from 8 to 12 per cent. of bitumen, according to its place of origin.

The amount of bitumen present determines the value of the rock for asphalt paving ; there should not be less than 7 per cent. or more than 12 per cent. Too much bitumen produces a soft and *creeping* surface, while too little will not furnish the binding power necessary to withstand heavy traffic. The percentage of bitumen present in a specimen of rock can be determined by dissolving it in carbon bisulphide and evaporating the solution. The bitumen remains, and, after exposing it to a temperature of 220° C. to drive off any volatile oils that may be present, can then be weighed.

6. **Compressed asphalt.**—For heavy traffic, the rock asphalt is laid in the form known as compressed asphalt. The natural rock asphalt is broken into small pieces of about 1-inch gauging, which in turn are ground into a powder fine enough to pass through a $\frac{1}{10}$-inch mesh. The powder is heated to a temperature of about 130° C. in revolving cylinders, and taken to the site of the work as quickly as possible, every precaution being taken to ensure that it cools as little as possible before it is laid.

7. **Mastic asphalt** is a preparation made from powdered rock asphalt, and is used where lighter traffic only is anticipated and for footways. Refined Trinidad bitumen is first melted and the powdered rock is added gradually, the whole mass being well stirred at a temperature between 200° and 250° C. for about five hours.

The resulting mixtures may either be laid at once, or allowed to set into blocks and remelted when and where required. The proportion of free bitumen varies according to the climatic conditions of the locality where the asphalt is to be laid, and also depends on the amount of bitumen present in the rock asphalt being used; from 5 to 8 per cent. of the total required is an average figure.

8. The advantages of asphalt as a road surface are:—

(i) Smoothness.
(ii) Cleanliness.
(iii) Durability; it will last from 10 to 18 years under normal traffic.
(iv) It keeps a uniform surface.
(v) It produces a minimum of noise.
(vi) It affords easy traction.
(vii) It is easily laid and the cost of maintenance is low.

Its disadvantages are:—

(i) Heavy initial cost; concrete foundations are always essential.
(ii) It is unsuitable for any but very slight gradients.
(iii) It is slippery and liable to cause skidding.
(iv) It melts in hot climates, and *creeps* if on a slope greater than 1 in 60.

The progress made in recent years with regard to the use of bituminous materials for road surfaces has been very rapid, and there has been a corresponding increase in the amount of literature produced on this subject. Definitions of the various terms used in civil practice have not yet been standardized, but the foregoing brief description will suffice to draw attention to the various forms in which those materials are applied; detailed information is to be found in the standard text-books on modern road construction.

APPENDIX VI.

Wood blocks.

1. Timber, in the form of wood blocks, is extensively used in the paving of city streets. It is very seldom that such a form of paving will be necessary in military work; nevertheless, a few remarks regarding this material are given.

2. There are several kinds of timber, commercially grouped under hard and soft woods, suitable for use as wood blocks; the latter are preferable, and are gradually superseding the former. Of the hard woods in general use, the most favoured are the Australian woods known as Jarrah, Karri, and Blackbutt. These are durable and very closely grained, and can be used without creosoting; they are less absorbent than the soft woods, consequently providing a sanitary pavement, and the expansion due to moisture is not so apparent. Hard woods have come into disfavour chiefly on account of their tendency towards uneven wear and the slippery nature of the surface produced. The soft woods employed in paving are Baltic firs. These are very absorbent, and cannot be used without previous treatment against decay; the blocks do not last so long as those of the hard woods, but possess the advantage of more even wear; they are also quieter, and the initial cost is less. They may be taken up and relaid after dressing, so long as the wear does not exceed 2 inches. Blocks are always laid with the grain vertical.

3. The size of the blocks, which should be rectangular, varies between 6 to 9 inches in length, 3 to 5 inches in width, and 3½ to 5 inches in depth, according to the kind of timber used. It has been found that narrow blocks give a better foothold in wet weather. A soft wood block must be deeper than a hard one, and the figure of 3½ inches is only suitable for the hardest wood. It is necessary to renew all blocks after about 2 inches of wear, consequently a thickness greater than 5 inches is uneconomical.

4. **Wood preservation.**—Creosote is the most common preservative against decay in timber, and is obtained by the distillation of coal-tar. It should contain at least 8 per cent. of tar acids. The difficulty in treating the wood blocks with creosote is to ensure complete penetration; unless the timber is thoroughly saturated the centre of the block remains untreated, and internal decay will not be prevented. The process known as *Bethell's* is the most effective. The blocks are placed in an airtight cylinder, from which the air is removed by pumping until the pressure is reduced to about ⅛ of an atmosphere; the creosote is then admitted at a temperature of about 100° C., by means of a pressure pump, until the blocks have absorbed 10 lbs. per cubic foot. A sample block should be cut through and examined to ensure that the creosote has penetrated to the centre.

APPENDIX VII.

Concrete.

1. Apart from its uses in bridges, culverts, retaining walls, and other constructional work in connection with roadways, cement concrete has for many years been used as a foundation for asphalt, wood block, and sett pavements, and such a foundation is now considered essential. Some form of reinforcement is generally incorporated with the concrete when laying a foundation over bad ground. More recently, and particularly in America, concrete has been introduced to form the road surface itself; experiment is still proceeding, and successful results have been obtained, particularly when reinforced concrete has been used.

2. **Materials.**—The following are essential points to be noted in the selection and preparation of materials:—

(i) The *sand* must be coarse and clean; it must be free from all impurities, earth, or clay. Sand may be tested for organic impurities by shaking with sodium hydroxide, and allowing the liquid to stand for 12 hours when it should remain colourless.

(ii) The *cement* should be of British Standard specification for slow setting. It should be capable of withstanding a tensile stress of not less than 400 lbs. per square inch when mixed neat with 20 per cent. of its own weight of water and allowed to stand 1 day in air and 7 days in water. Its fineness should be such that not more than 3 per cent. of residue is left on a sieve of 5,776 meshes per square inch. The specific gravity should not be less than 3·15.

(iii) The *stone* must be sharp and clean; granite chippings are preferable if they can be obtained. The gauging should be from ½ inch to 1½ inches, but the larger stones should not be in greater proportion than 60 per cent.

(iv) *Water* should be clean and fresh; it should be used sparingly, and the mixture should be plastic; a wet mixture produces a weak concrete. A volume of water equal to about 75 per cent. of the volume of cement will usually suffice; it should be applied to the dry mixture through a rose or spray.

3. **Proportions.**—The following proportions are recommended for different classes of work:—

(i) For concrete used in the foundations of bridges, culverts, retaining walls, &c.:—4 parts coarse aggregate, 2 parts fine aggregate, 1 part cement, all measured by volume. The coarse aggregate can be broken stone up to 2½-inch gauging, and the fine aggregate from ¼-inch gauging down to fine sand.

(ii) For concrete used in foundation of paved roads:—4 parts coarse aggregate, 2 parts fine aggregate, 1 part cement, all measured by volume. The coarse aggregate should be good hard broken stone from 1½ to ¼-inch gauging. The fine aggregate should be from ¼-inch gauging down to fine sand.

Gravel, combining coarse and fine aggregate, can be used and the proportion of cement should be 1 part to 4 parts mixed gravel.

(iii) For concrete used in the construction of cement concrete roads with or without reinforcement (*see* para. 4):—3 parts coarse aggregate, 2 parts fine aggregate, 1 part cement, all measured by volume. The coarse aggregate should be broken stone from 1½ to ¼-inch gauging. The stone must be good hard stone. The fine aggregate should be ¼-inch gauging down to fine sand.

The concrete in all cases should be mixed as dry as possible, so long as a workable mixture is obtained. Machine mixing is always superior to hand mixing, and should invariably be employed for cement concrete roads. When hand mixing is employed, the mixture should be turned twice dry and twice wet.

A granite concrete topping 1½ inches thick forms an excellent surface for any concrete road, but there is no need for it if the concrete generally is made with a good hard stone aggregate. Granite chippings crushed to pass through a ⅜-inch mesh are used in this topping, which should be laid immediately after the lower part is laid and before it has begun to set.

4. **Reinforcement.**—There are various methods of reinforcement in use. Expanded metal of large mesh is a common form, and makes a good reinforcement; steel wire of about $\frac{3}{16}$ inch in diameter, cross welded with a mesh of 6 inches by 3 inches or thereabouts, is excellent.

The fabrics of the British Reinforced Concrete Engineering Company are in general use for road-work. Their No. 9 fabric is suitable for heavy traffic; this consists of transverse and longitudinal steel wires, at 12-inch and 3-inch centres respectively, laid about 2 inches above the bottom of the concrete; the longitudinal wire is of No. 5 gauging (Imperial Standard) and has a sectional area of 0·0353 square inch; the transverse wire is of No. 10 gauge. The same firm also supply lighter reinforcement for use when heavy traffic is not anticipated. These fabrics are supplied in rolls 240 feet long and 7 feet wide.

The ultimate tensile stress for reinforcing metal is laid down at 60,000 lbs. per square inch, and the wire is generally required to be capable of being bent completely round itself and re-straightened without fracture.

APPENDIX VIII.

Miscellaneous materials.

1. Under this heading are included such materials and stores as are likely to be obtainable locally or made available for the construction of forward roads and tracks, by means of which as good a surface as possible can be provided in minimum time.

The following are useful varieties:—Fascines, timber, corduroy road-matting, wire netting, rubble, sandbags, tibben, reeds, charcoal, and clinker.

2. **Fascines** are lengths of brushwood tightly bound into bundles about 9 inches in diameter; particulars of their construction are given in Manual of Field Works (All Arms), Chap. II.

The length laid down, 18 feet, is satisfactory when the fascines can be made close to the work and pontoon or trestle wagons used to carry them to the site, as it enables a double-way road to be laid without a longitudinal joint, but 10 feet has been found to be a more convenient length for transport and handling where the fascines have to be carried long distances, or are stored in engineer parks for issue as required.

Fascines are extremely useful in marshy ground, and in making up the softer lengths of cross-country tracks.

3. **Timber** is chiefly used in forward areas for the laying of corduroy and plank roads. (Sec. 29.)

The surface of *corduroy roads* consists of closely laid round logs from 4 to 6 inches in diameter, which are kept together by a riband of similar or squared timber. Ten feet is a convenient length for handling. Any kind of straight timber of the required thickness will serve, but larch, spruce, and fir are the best, as these usually provide very straight logs with gradual taper. When the poles are to be obtained locally, a felling party will be required to keep the road party supplied.

Half-round corduroy, of 10 to 12 inches in diameter, can be used as above, and it also makes a good foundation for a gravel road for light traffic.

The surface of *plank roads* is similar in principle to corduroy roads, the material being any hard wood cut into planks 2 inches in thickness and about 10 feet in length. Beech provides the best surface, and the planks are, therefore, known as *beech slabs*. Their preparation can seldom be undertaken by forward troops, unless access to a saw mill in the neighbourhood of a forest is obtained. They are usually sent forward from an engineer park by rail or lorry, and drawn from forward dumps by the troops employed on the work as required.

For the longitudinal runners and transverse bearers of corduroy and plank roads, 8-inch round timber or 9 by 3-inch planking is suitable.

Corduroy road-mats.—A useful form of corduroy road can be constructed, where workshops are available, from timber made up into what are known as *corduroy road-mats*, which are convenient to handle and rapidly laid (Sec. **33**). The most convenient size is 8 feet 6 inches by 3 feet 6 inches. The larger poles, of about 6 inches diameter, are halved lengthways, usually by means of a mechanical saw. These half-poles are cut into 3-foot 6-inch lengths, and fastened to three stringers of similar timber, or of beech slabbing, to form a road-mat. The ends of the stringers are arranged so that each mat will fit into the ones adjacent to it.

Pl. **49** shows the details of a corduroy road-mat. The method of manufacture is as follows :—The stringers are first fixed in position on a bench by means of a gauge ; the first cord at the male end of the stringers is nailed down, and a temporary one is fixed at the other end. The remaining cords are fixed by means of stout wire, used in the form of a *malay hitch*, the wire being looped round the outer stringers at intervals, and stapled to the cords and stringers as shown. A stout wire ring of not less than $2\frac{1}{2}$ inches diameter is inlet at opposite corners of the mat, by means of which it can be securely picketed to the ground.

4. **Wire netting** is often used for passing the lighter types of vehicles and foot traffic over loose sand. The common round-mesh netting, issued in rolls and known as *rabbit wire*, is employed. The mesh should not exceed one inch in diameter. Plain wire and pickets are used for anchorage purposes. (Sec. **31**.)

Wire netting, used in alternate layers in conjunction with sandbags, is useful for the temporary filling of shell-holes.

5. **Rubble** is used in repair work on forward roads, but should only be resorted to when other material is not readily available and the passing of transport across shelled areas is urgent. It will usually be obtained from demolished buildings in the vicinity, and in all important operations troops and transport should be detailed for this work.

6. **Sandbags** are useful in the hasty repair of shell-holes or craters (Sec. **36**). They should be carried by repair and maintenance parties during operations.

7. **Tibben** is chopped straw, and has been successfully used in desert countries both as a foundation for light metalled roads and as a surface for light traffic (Sec. **31**). It must always be well watered and rammed.

8. **Charcoal** may be used in forest country where the timber is not suitable for corduroy roads; it makes a very compact surface for light traffic, and can be prepared on the site.

9. **Reeds**, and similar materials such as millet-stalks (*Kaoliang*—China, and *Moonj*—Upper Sindh), are used in a similar manner to fascines on dry sandy plains.

10. **Clinker** and **ashes** are good materials for light roads, but they are not durable, and require constant attention. The clinker should be well-burnt refuse-destructor clinker, unscreened, but free from metallic substances.

11. **Materials for screening from observation.**—Stout poles of various lengths, wire netting, canvas, brushwood, plain wire, and pickets are the principal stores used. (Sec. **38.**)

APPENDIX IX.

Tools.

1. **Supply.**—On active service the source of supply of tools for road-work is similar to that of other engineer stores; they are stocked in base parks, and forwarded to army and corps engineer parks, the latter distributing them to divisional engineer dumps according to the requirements of each division.

2. **Stock in dumps.**—Apart from special machinery and plant required for use on the Lines of Communication or in rear areas (for the supply of which special arrangements are made), the following list of tools is given as a guide for road making, and these tools should be found stocked in all engineer parks and dumps in sufficient quantities to meet demands anticipated:—

Adzes.
Axes, felling.
,, hand.
,, pick, with helves.
,, ,, heads.
Augers, carpenters'.
Barrows, wheel.
Bars, jumping.
,, tamping.
Brooms, bass, with handles.
,, ,, heads.
Chisels, carpenters'.
Crow-bars.
Files, saw.
Forges, portable.
Hammers, sledge.
,, stonebreaking.
Hose, suction.
,, delivery.
Levels, field.
Mallets, carpenters'.
Masons' tools (in sets).
Mauls.
Oilstones, carpenters'.
Pans, warming, dynamite (for cold climates).
Pliers.
Pumps, L. and F.
Rammers, iron.
Saws, hand,
,, hack.
,, cross-cut.
Saw-sets.
Scrapers, road, wood.
,, ,, iron.
Shovels, G.S.
,, R.E.
Smiths' tools (in sets).
Spanners.
Spokeshaves.
Spoons, blasting.
Tapes, measuring.
,, tracing.

3. **Requirements for native labour.**—In mountainous or undeveloped country, where blasting may be required, the supply of tools will present difficulties unless careful arrangements are made beforehand. The delivery at rail-head will, as a rule, be up to date, but the transport beyond must be early organized, and experienced store-keepers engaged. An ample supply of portable forges and smiths' tools should be included in order to keep the jumpers in repair. Before indenting for, or purchasing, tools it is desirable to ascertain personally what rock or soil is likely to be met with, and what proportion of blasting tools and explosive will be required: some gravels are more expeditiously loosened and removed by explosives than with picks.

The following is a list of requirements for 100 coolies, working in an average country with a few trees and a certain amount of rock :—

Adzes	6
Axes, felling	12
Axes, hand or *kukris*	30
Axes, pick	60
Bars, jumping, 1½ inches	15
Bellows, braziers, small...	2
Bellows, smiths': or forges, portable	2
Baskets for earthwork: or barrows, hand	100
Carpenters' tools	2 sets
Crow-bars	6
Hammers, masons'	6
Hammers, sledge	6
Hammers, stonebreaking	12
Knives, clasp	6
Native hoes (*phourahs**): or shovels, G.S., with cords	65
Tapes, steel (100 ft., 50 ft., and 25 ft.)	3
Smiths' tools	3 sets
Spare helves (short and long)	80
Trowels, masons'	6
Wedges, steel	36

* Mamootie is another name for the same tool.

In addition, 20 per cent. should be obtained as a reserve in case of delay in getting supplies for replacement of losses.

If much rock is anticipated an ample supply of jumping bars, sledge hammers, crow-bars, &c., should be obtained. Two smiths and two carpenters will be required to keep the above tools in order. Local wood, if available, can very often be utilized for helves and manufacture of charcoal, otherwise arrangements for these will be necessary.

Tools to which the natives are accustomed must be taken ; for example, an African and some races in India must be given baskets or hand barrows. Many natives do not understand spades, and are usually barefooted; therefore, native *phourahs* or hoes must be obtained. Others, such as those on the N.W. Frontier of India, work well with shovels, with two men to each shovel, one using the handle and the other working in front of the shovel pulling a rope attached to the handle just above the junction with the blade. Store-keepers must keep a very careful check on the issue and receipt of all tools and plant, and 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; a practical test beforehand is the best guide, as not every steel is suitable.

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

INDEX.

A

B

D

Q

R

T

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GRAND TRUNK ROAD, INDIA.

1,500 MILES, CALCUTTA TO PESHAWAR.

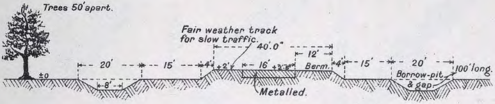


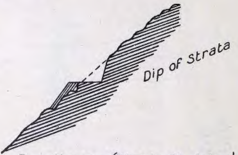
Plate 1.

Malby & Sons, Lith.

Plate 2.

INCLINATION OF STRATA.

Fig. 1.

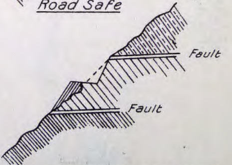


ROAD UNSAFE (Strata Shelving)

Fig. 2.

Road Safe

Fig. 3.



Stratification Favourable, but Road Unsafe on Account of Faults.

Malby & Sons Lith.

ZIGZAGS.

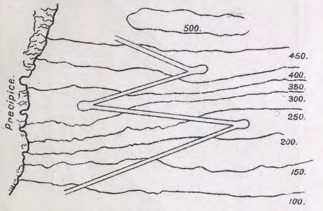


FIG. I. RETURNS ON ZIGZAG.

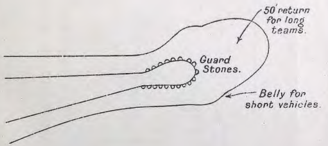


FIG. 2. PLAN OF TURNING POINT.

Malby & Sons, Lith.

EXAMPLE OF PAPER LOCATION.

LON

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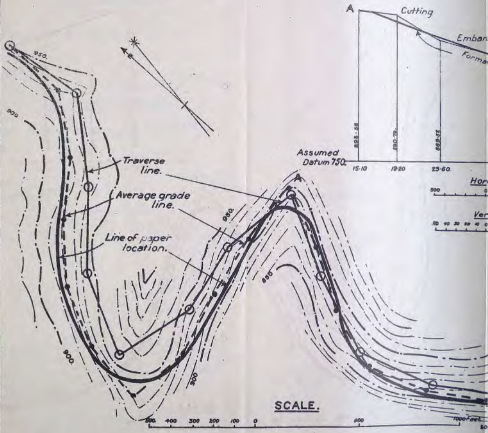
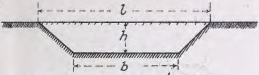


NOTE:- *In practice, the line finally chosen will coincide with the average grade line*
is shewn above; the divergence from it is accentuated in order to show the th

73. 7261 4730/211.

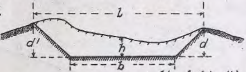
COMPUTATION OF EARTHWORK — I.

Fig. 1.



Sectional Area $A = \frac{h}{2}(l+b)$

Fig. 2.

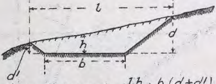


Sectional Area $A = \frac{lh}{2} + \frac{b}{2}\left(\frac{d+d'}{2}\right)$

Fig. 3.

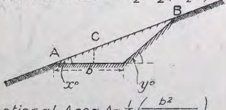
Sectional Area $A = \frac{lh}{2} + \frac{b}{2}\left(\frac{d+d'}{2}\right)$

Fig. 4.



Sectional Area $A = \frac{lh}{2} + \frac{b}{2}\left(\frac{d+d'}{2}\right)$

Fig. 5.



Sectional Area $A = \frac{1}{2}\left(\frac{b^2}{\cot x - \cot y}\right)$

COMPUTATION OF EARTHWORK—2.

FIG. 1.

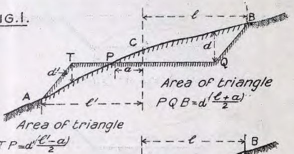
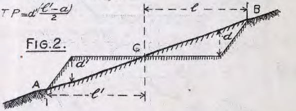
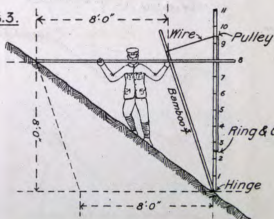


FIG. 2.



Equal triangles, formula as above $a = 0$

FIG. 3.



SLOPE TEMPLET.

Malby & Sons. Lith.

SETTING OUT CURVES-I.

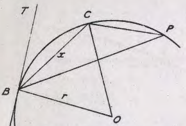


Fig. 1. Properties of a circular curve.

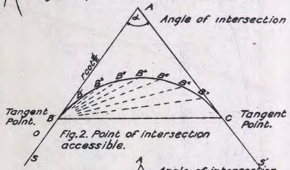


Fig. 2. Point of intersection accessible.

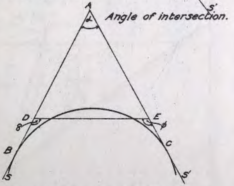


Fig. 3. Point of intersection not accessible.

SETTING OUT CURVES–2.

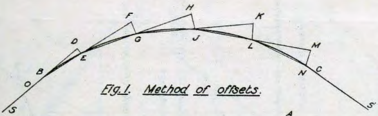


Fig.1. Method of offsets.

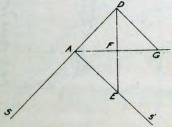


Fig.2.

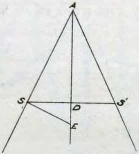
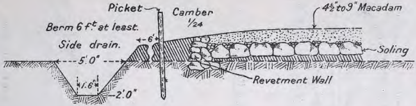


Fig.3.

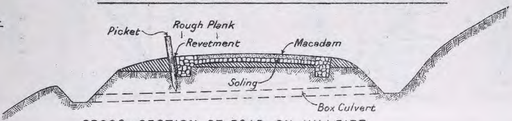
SIDE DRAINS AND REVETMENTS.

FIG. 1.



SECTION SHEWING DRAIN & REVETMENT WALL.

FIG. 2.



CROSS-SECTION OF ROAD ON HILLSIDE.

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Plate 9.

SETTING OUT CURVES-2.

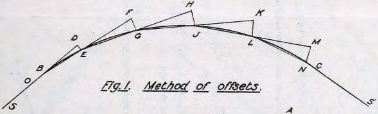


Fig.1. Method of offsets.

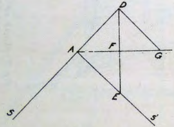


Fig.2.

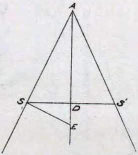
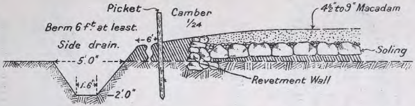


Fig.3.

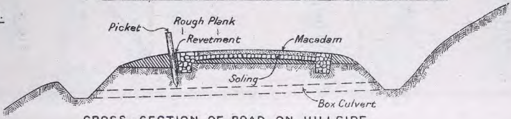
SIDE DRAINS AND REVETMENTS.

FIG. I.



SECTION SHEWING DRAIN & REVETMENT WALL.

FIG. 2.



CROSS-SECTION OF ROAD ON HILLSIDE.

Plate 9.

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CATCH-WATER DRAINAGE.

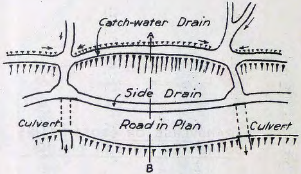

FIG. I. PLAN.

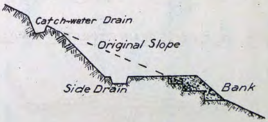

FIG. 2. SECTION ON A B.

DRAINAGE OF SUBGRADE.

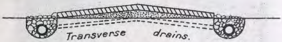

FIG. 1. TRANSVERSE OR CROSS-DRAINS CONNECTED TO SIDE DRAINS.

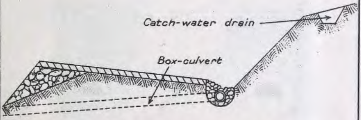

FIG. 2. SINGLE SIDE DRAIN CONNECTED TO BOX-CULVERT.

FIG. 3. CENTRAL DRAIN.

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COVERED DRAINS.

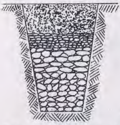

FIG. 1. BLIND DRAIN.

FIG. 2. TILE DRAIN.

FIG. 3. BOX-DRAIN SQUARE.

FIG. 4. BOX-DRAIN TRIANGULAR.

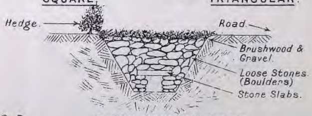

FIG. 5. DITCH, COUNTRY ROAD WITH BLIND DRAIN.

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SECTION OF A WATER-BOUND MACADAM ROAD

SEE SECTION 22.

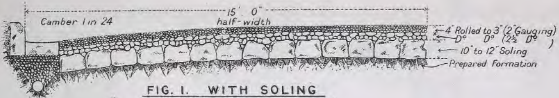

FIG. 1. WITH SOLING

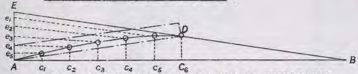

FIG. 2. CONSTRUCTION OF ROAD TEMPLET

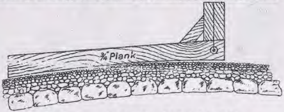

FIG. 3. ROAD TEMPLET

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Plate 13

SIDELONG SLOPES.

Fig. 1.

Fig. 2.

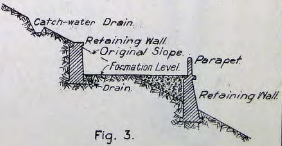

Fig. 3.

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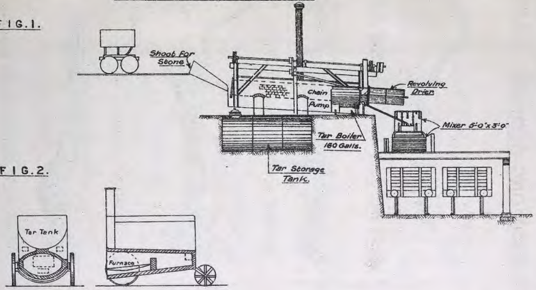
TAR MACADAM PLANT.

FIG. 1.

FIG. 2.



Tar Boiler

Plate 15.

Fig. 1 Reproduced from "Practical Stone Quarrying" by Permission of Messrs Crosby Lockwood and Son, 7, Stationers' Hall Court, London, E.C.4.

Fig. 2 Reproduced from "Modern Road Construction" by Permission of the Publishers, Messrs Charles Griffin and Co., Ltd., Exeter Street, Strand, London, W.C.2.

IMPROVEMENT OF COUNTRY ROADS.

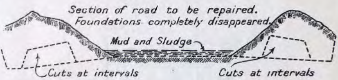


FIG. 1. TYPICAL SECTION OF SUNKEN COUNTRY ROAD.

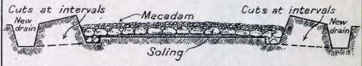


FIG. 2. SUNKEN COUNTRY ROAD REMADE.

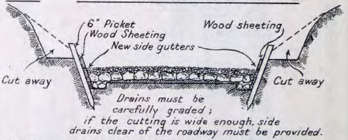


FIG. 3. TREATMENT IN DEEP CUTTING.

FIG. 4. METHOD OF WIDENING PAVE ROAD.

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TIMBER ROAD SECTIONS.

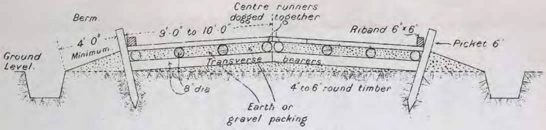

FIG. 1. CORDUROY ROAD.

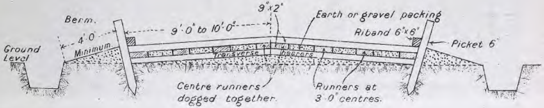

FIG. 2. PLANK OR SLAB ROAD

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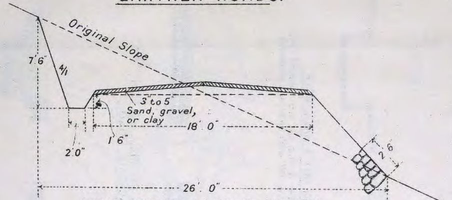
Plate 17

Plate 18.

Construction of Desert Road with Wire Netting.

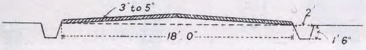
EARTHEN ROADS.

FIG. I.



CROSS-SECTION ON STEEP HILLSIDE

FIG. 2.



CROSS-SECTION ON LEVEL GROUND

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REPAIR OF SHELL-HOLES.

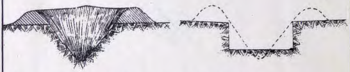

FIG. 1. CUTTING OUT A SHELL-HOLE.

Remove all water & mud, cut out square & ram the bottom of hole; fill with sandbags properly laid in courses.

FIG. 2. REPAIR OF SHELL-HOLE IN MACADAM ROAD.

FIG. 3 REPAIR OF LARGE SHELL-HOLE WITH TIMBER CRIB.

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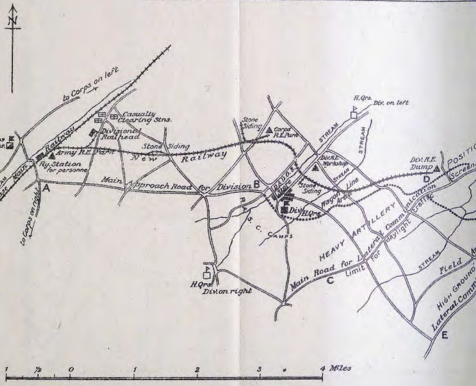
TYPICAL EXAMPLE OF FORWARD ROAD SY



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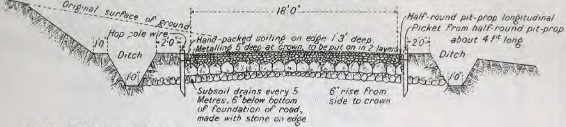
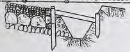
CROSS-SECTION OF NEW ROAD
CONSTRUCTED BETWEEN POINTS A AND B ON PL. 21.



PLAN AT SIDE OF ROAD IN CUTTING

CROSS-SECTION
Showing strutting where necessary



PLAN SHOWING STRUTTING WHERE NECESSARY

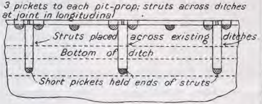


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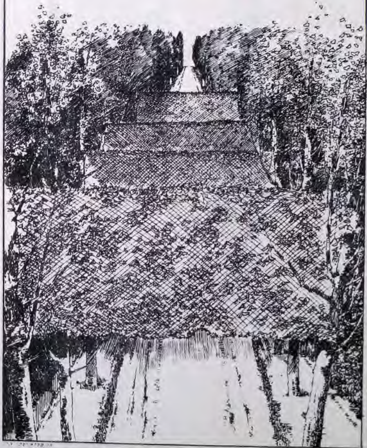
Plate 22

Plate 23.

SCREENING FROM ENFILADE VIEW.

TRAFFIC TO PASS UNDER SCREENS.



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SCREENS IN ECHELON.

FOR ROAD PARALLEL TO FRONT LINE.

Enemy view of road unscreened.

After screening

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Plate 24.

SCREENS IN ECHELON.

FOR ROAD OBLIQUE TO FRONT LINE

Enemy view of road unscreened

After screening

7261. 4730 2/1

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MOUNTAIN ROAD SECTIONS–I.

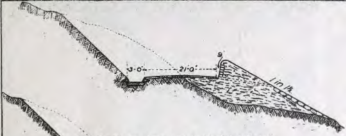

Fig 1. For slopes from level to 1 in 2 in soft soil.

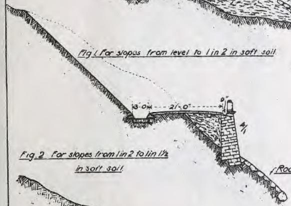

Fig. 2 For slopes from 1 in 2 to 1 in 1½ in soft soil.

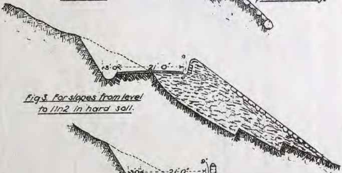

Fig 3. For slopes from level to 1 in 2 in hard soil.

Fig 4. For slopes from 1 in 2 to 1 in 1½ in hard soil

Plate 27.

MOUNTAIN ROAD SECTIONS-2.

Fig.1. Neutral Section.

Fig.2. Embanked Section.

Fig.3. Cutting Section.

Fig.4. Saddle Section.

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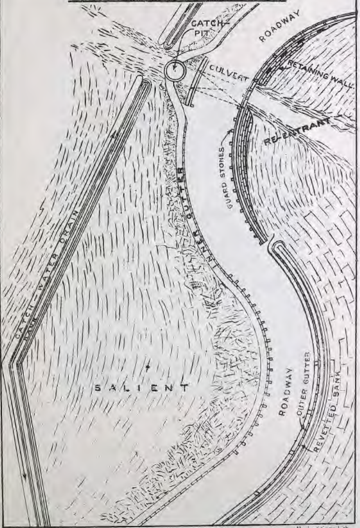
MOUNTAIN ROAD DRAINAGE.



A MOUNTAIN MILITARY ROAD.

HALF – TUNNELS.

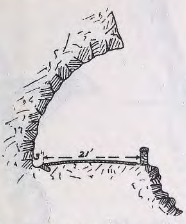


Fig.1. Section of Half-Tunnel.

Fig.2. Bore-holes for End Attack.

Fig.3. Bore-holes for Face Attack.

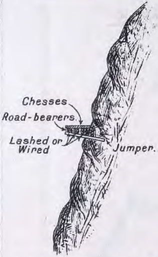


FIG. 1. CLIFF GALLERY– TEMPORARY TRACK FOR FOOT TRAFFIC.

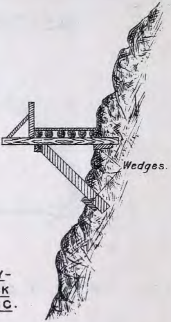


FIG. 2. CLIFF GALLERY FOR PACK TRANSPORT.

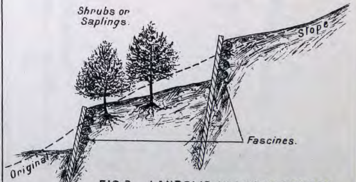


FIG. 3. LANDSLIP IN LOOSE STRATA.

CLIFF CRADLE.

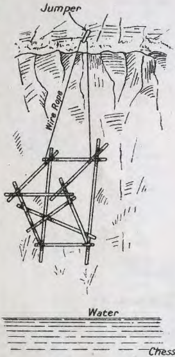


FIG. 1.

CRADLE.

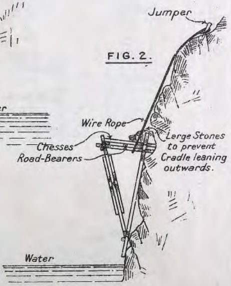


FIG. 2.

SECTION OF PRECIPICE & CRADLE IN POSITION.

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CLIFF GALLERY.

FOR HORSE TRANSPORT AND LIGHT MOTOR CARS.

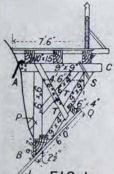


FIG. I

Transverse section of cradle and roadway above it.

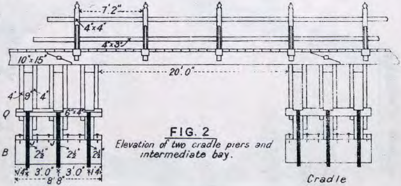


FIG. 2

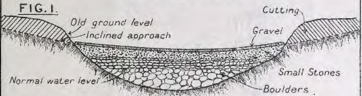
Elevation of two cradle piers and intermediate bay.

A. Is a bent Jumper 3'.0" long of which 18" are let into the cliff & 18" secured to the capping piece
B. Sill block 2'.6" deep.
C. Cradle Cap or capping piece 9"x9"
J. Stanchions of bar iron 2½ square
P. Cradle posts 9"x9"
Q Stanchion Cap 6"x4"
S. Cradle Struts 9"x9"
T. Braces are notched into struts and capping piece.

The distance apart of the cradle piers will not always be uniform, it may vary from 15 to 25 feet. As a rule, 18 to 20 feet is found the most convenient distance.

CAUSEWAYS.

FIG. 1.



CROSS-SECTION OF CAUSEWAY

FIG. 2

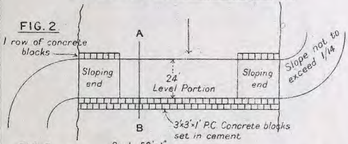
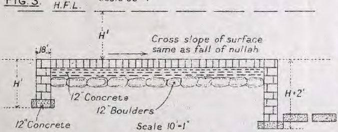


FIG. 3.



SECTION ON A.B

FIG. 4.

IRISH BRIDGE

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TYPES OF SNOW SHEDS.

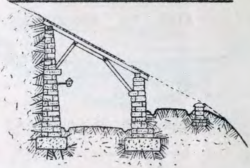

Fig. 1.

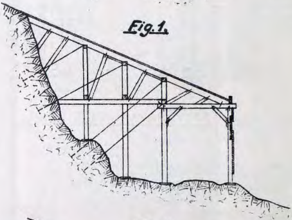

Fig. 2.

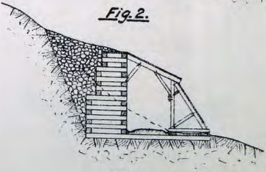

Fig. 3.

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REPAIRS TO BRIDGES.

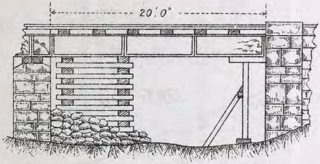

FIG. I. TEMPORARY REPAIR OF GIRDER

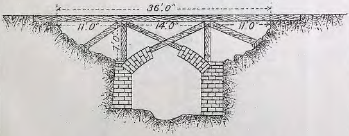

FIG. 2. HASTY REPAIR OF MASONRY ARCH.

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SCOUR.

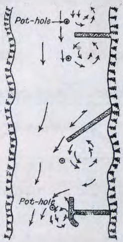

Fig. 1. *Formation of Pot-hole*

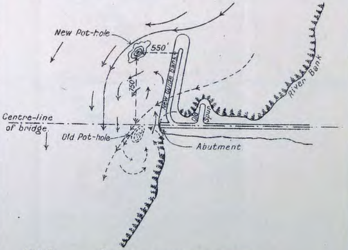

Fig. 2. *Removal of dangerous Pot-hole by construction of new guide bank*

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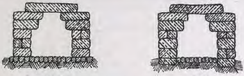
BOX-CULVERTS.



"A" "B"

Fig. 1. Stone slab culvert. "A" wrong method. "B" right method.

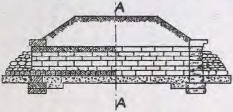


Fig. 2. Stone Box-Culvert Elevation.

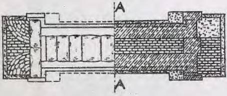


Fig. 3. Stone Box-Culvert Plan.

Fig. 4 End Elevation.

Fig. 5. Section A.A.

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MOUNTAIN ROAD CULVERT.

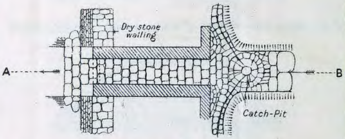

FIG. 1. PLAN

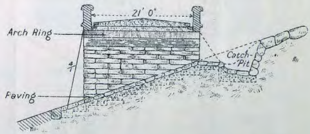

FIG 2 SECTIONAL ELEVATION ON A.B

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PIPE-CULVERTS.

Fig. 1. *Stoneware Pipe-Culvert.*

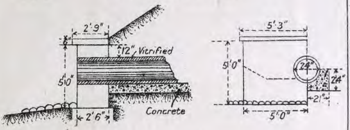
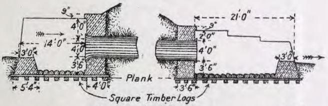
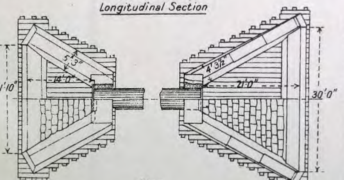


Fig. 2. *Iron Pipe-Culvert.*



Longitudinal Section



Plan.

TYPICAL CULVERT OR ARCH.

FIG. 1.

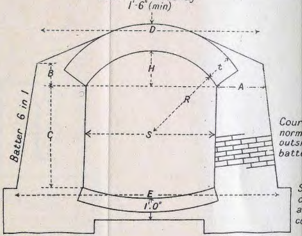
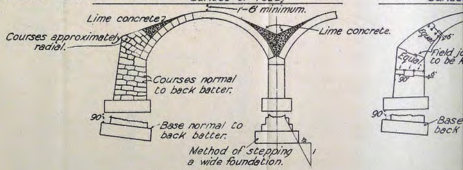


FIG.2. CONSTRUCTION DETAILS.



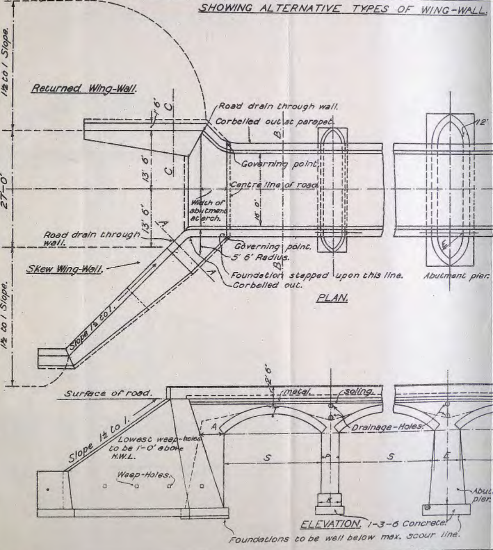
MASONRY ARCH.

P.C. CON

73.7261. 4750/24.

TYPE DETAILS FOR ARCH BRIDGES OF 10 TO 5C

SHOWING ALTERNATIVE TYPES OF WING-WALL.



73. 7261. 4730/2//.

CENTERING FOR ARCHES.

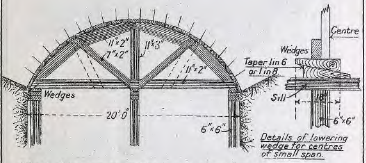


Fig. 1. *Showing scantlings and arrangement of centres for a bridge of 20 feet span.*

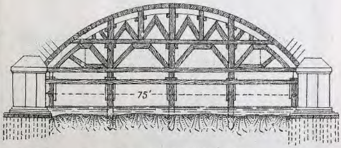


Fig. 2. *Type of centre for large span.*

Malby & Sons, Lith.

SECTIONS OF PAVED ROADWAYS.

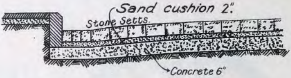


Fig. 1. Stone Setts.

Fig. 2. Asphalt . with binder course.

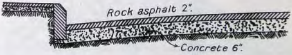


Fig. 3. Rock Asphalt.

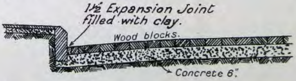


Fig. 4. Wood Blocks.

73.7281. 4730/211
Malby & Sons Lith.

Plate 45.

Reinforced Concrete Road under Construction (W. D. Hutment).

[Reproduced by permission of the British Reinforced Concrete Engineering Co., Ltd.

KERBS AND GUTTERS.

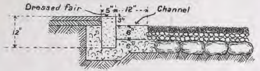


FIG. 1. STONE KERB AND CHANNEL.

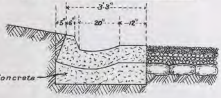


FIG. 2. ST. LOUIS CONCRETE KERB AND GUTTER

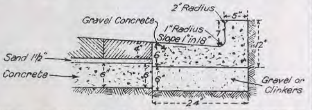


FIG. 3. STANDARD CONCRETE KERB & GUTTER

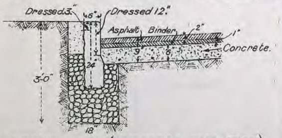
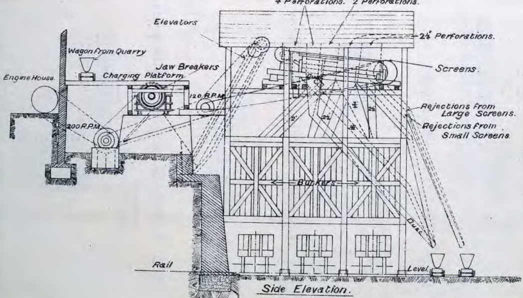


FIG. 4. STONE KERB (AMERICAN PRACTICE)

Plate 47.

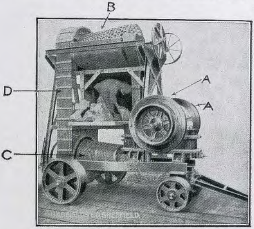
QUARRY PLANT.



Side Elevation.

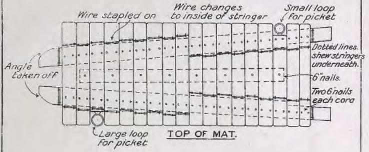
Reproduced from "Practical Stone Quarrying" by permission of Messrs. Crosby Lockwood and Son, 7, Stationers' Hall Court, London, E.C.4.

MOBILE STONE BREAKING AND SCREENING PLANT.



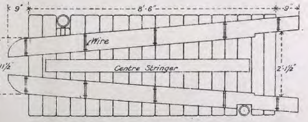
[*Reproduced by permission of Messrs. Hadfields, Ltd., Tinsley, Sheffield.*

CORDUROY ROAD-MAT.



TOP OF MAT.

ELEVATION.



PLAN BOTTOM OF MAT.

MATERIAL REQUIRED

Two ½ round stringers 10'-0" long.
One do do 7'-0" — do —
Eighteen pieces ½ round corduroy 3'-6" long.
120 Iron staples (1¼" or 1½").
80 6" Nails.
25 Yds. ¼" wire. No. 4. S.W.G.

(As to prices in brackets, see top of page 2.)

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