SECTION IV

Building the Road II - Construction
1. Introduction

The examination of the techniques employed in the construction of the Great North Road is the study of an imported technology and thus requires a survey of contemporary English methods. Through the comparison of the two, the process of adoption and adaptation of both English theory and practice may be discerned and discussed, and the nature of colonial engineering understood.

The two difficulties with this approach concern the bibliographical resources. First, while there is an abundance of information concerning nineteenth century road building in the forms of treatises, manuals and essays, little of it dates from the 1810's and 1820's. The problems connected with this are to some extent negated by the second point, that is that the date of publication of a nineteenth century book about road building is not always a reliable guide for dating the technology contained in it. To ascertain the relevant contemporary English technology for an 1820's and 1830's colonial road, it is in fact necessary to examine texts dating from later in the nineteenth century.

These problems arise partly from the fact that nineteenth century engineers tended to formulate and practice their respective theories for some time before they recorded their methods in books. Thomas Telford, who built roads during the late eighteenth and early nineteenth century's did not write his autobiography until the 1830's and it was not published until 1838, after his death four years earlier. (1) MacAdam's major works Remarks on the Present System of Road Making did not appear until 1824, although he too had apparently practiced since before the turn of the century. (2) A lesser work, A Practical Essay on the Scientific Repair and
Preservation of Public Roads was however available from 1819. (3) One other early English reference book was J.L. Edgeworth's *An Essay on the Construction of Roads and Carriages*, first published in 1788 and reprinted in 1817. (4) Students of road construction may possibly also have had access to earlier European works, such as Nicholas Bergier's *Histoire des Grand Chemins de L'Empire Romain* (1622) and Gautier's *Traite de la Construction des Chemins* (1693).

However, since there was no central educational institution for road engineers in England (such as the Corps des Ponts et Chausées in France) it is likely that, in the early nineteenth century at least, they acquired their knowledge primarily by example rather than from books. Forbes claims that "Civil engineers trained their pupils on the road itself". (5) John Metcalfe devised techniques which became widely known, although he never actually published them himself. (6) In R.S.W. men such as Assistant Surveyors Elliot and Lambie were reputed to have worked with Telford and MacAdam respectively and were considered expert road engineers. (7) It appears therefore that many colonial engineers had also gained their knowledge of road building in this informal manner, learning by practice, experience and word of mouth, rather than formally from books.

From the 1830's, in the wake of the success of Telford and MacAdam and the subsequent revival of interest in road building, a flood of technical information was published, beginning with Parnell's *Treatise on Roads* (1838), (8) and continuing to the early twentieth century. The outstanding characteristic of this body of material is its high degree of consistency with regard to the theories and methods described. Both lengthy acknowledged citation and outright plagiarism of the work of Telford, MacAdam and other contemporary authors
are common, with the result that the various works from throughout the nineteenth century are extremely repetitive in content. Henry Parnell mainly described and expanded the theories of Thomas Telford, and he himself was later widely cited. Burgoyne's Remarks on the Maintenance of Macadamised Roads (reprinted 1857) largely repeated directives given by MacAdam. (9) The entry under "Roads" in Tomlinson's Cyclopaedia of the Useful Arts (n.d., c1880's) contains information so universal as to be inconsistent, much of it taken from the work of MacAdam, Telford, Parnell and Law (1850). (10) D.K. Law also produced The Construction of Roads and Streets, of which a second edition appeared in 1881, in which he included information from Edgeworth (1788), Macadam (1824), Parnell (1833), Hughes (1838), Telford (1838) and Browne (1874). (11) William Gillespie in 1874 published A Manual of the Principles and Practice of Roadmaking Comprising the Location, Construction and Improvement of Roads and Railroads in New York. The preface outlined the American conditions:

The common roads of the United States are inferior to those of any other civilised country ... most (of these defects) arise from an ignorance either of the true principles of road making or of the advantages of putting these principles into practice. (12)

His book was intended to rectify these deficiencies and provided a useful condensed survey of contemporary English roadmaking practices, with recommendations for pavements taken from Macadam and Metcalfe, specifications for cuttings similar to those of Telford, and so on. The general character of nineteenth century road building books is thus better described as a compendium of knowledge to date rather than original work, although some authors included information about their own experiences.
With regard to fields related to road building such as blasting, quarrying and masonry, technical information given in such books as Burgoyne's *Treatise on Blasting and Quarrying Stone for Building and Other Purposes* (1868), (13) Dobson's *The Rudiments of Masonry and Stonework and Stonecutting* (1868), (14) Andre's *Book Blasting. A Practical Treatise* (1878), (15) Greenwood and Eladen's *Practical Stone Quarrying* (1913), (16) Tomlinson's *Cyclopaedia and Ure's Dictionary of Arts Manufactures and Mines*, (1853) (17) is again highly consistent. The authors frequently referred to the "traditional" nature of the techniques they described, reinforcing the relevance of these books to the earlier period.

The latter point is directly related to the second bibliographical problem set out above, concerning the lack of correlation between the date of publication and the date of introduction of a particular aspect of technology. It is evident from the above discussion that much of the nineteenth century material about road building had its origins in earlier works. The comparison of the methods described in these books with those used in the construction of the Great North Road, however, indicate that, while certain techniques were familiar to colonial road builders, and thus probably to their English counterparts, these techniques were not actually recorded in books until much later. For example, the use of projecting stone slabs to direct water from culvert away from retaining walls, although an obvious and simple measure, was not actually specified in any written source until Browne's article "Construction of Roads in Mountainous, Tropical Countries" appeared in 1874. (18) Similarly, one of the colonial engineers, Ogilvie proposed in 1835 to place guards or fenders on the surface of the roads to ensure the even distribution of traffic for proper
compaction. Again, this simple method was not described in a published work until Tomlinson's *Cyclopaedia* (c 1830). It thus again appears very likely that there was a large body of general information available to early nineteenth century engineers which was widely practiced and passed on by word of mouth. It was only as a result of the enthusiasm of later engineers that these techniques were recorded in books.

A related theme of the bibliographical resources is that the well known road builders, Telford and MacAdam, whose work dominated that of later engineers, were preoccupied mainly with the construction of durable, dry surfaces in England. They thus gave relatively little or no attention to other aspects such as drainage and masonry and the special problems of new roads in pioneer countries. Dobson's *Pioneer Engineering* (1877) (19) and Browne's article as cited above, are thus particularly useful in the context of the Great North Road, since they provide information about the experiences of military engineers in other colonial countries.

In a sense, therefore, most books about road building were one step removed from actual practice in the early nineteenth century - they were published only after the new theories had been developed and become fairly well-known. Since so few texts were written in the early nineteenth century, books generally apparently did not play a large role in the training of engineers. What was written later in the century was however a faithful and consistent record of those new theories developed by the road building pioneers. Therefore, in order to gain a complete and relevant picture of English road building practice, and hence the context for the Australian experience, it is necessary to survey the bibliographical material from the nineteenth century as a whole, and to
extract from this the general principles which would have formed part of the training of those engineers who arrived in Australia in the 1820's. To facilitate this survey of the considerable mass of often poorly organised information, the subject of road making has been divided into its numerous aspects, and the various methods associated with each will be discussed in detail, first in terms of British theory and second in terms of the colonial experience.
SECTION IV/2

INTRODUCTION

Notes


8. Henry Farnell, A Treatise on Roads Wherein the Principles on which Roads should be Made Explained and Illustrated by the Plans, Specifications and Contracts Made Use of by Thomas Telford, Eng. on the Holyhead Road, London, 1833.


2. British Theory

(1) Tracing

(a) General Principles

While earlier roads had been "old crooked horse tracks", apparently unplanned and haphazard, the road builders of the nineteenth century devoted much attention to the "proper" tracing of roads, according to various principles and always with the goal of the "perfect" road in mind. The nineteenth century road builder Henry Law wrote that:

The most perfect road is that of which the course is perfectly straight and the surface perfectly level. (1)

Tomlinson's Encyclopaedia echoed this ideal, although added a list of considerations qualifying it:

The ideal road (is) a perfectly straight and level surface, and perfectly smooth and hard ... The best road between two points is that which is shortest, the most level and cheapest of execution. But this general rule may admit of qualification for certain deviations may be rendered necessary by natural obstructions from hills, valleys and rivers, by the amount of traffic, for taking in certain towns and villages in the line of the road. (2)

Of course, most writers recognised that the perfectly straight and level road, although desirable, was rarely attainable. The American writer, Gillespie, actually recommended that low priority be given to directness:

... straightness should always be sacrificed to obtain a level or to make the road less steep. A straight road over an uneven and hilly country may be pronounced to be a bad road; for the straightness must have been obtained either by submitting to steep slopes in ascending the hills and descending into the valleys, or those natural obstacles must have been overcome by incurring a great and unnecessary expense in making deep cuttings and
fillings. (3)

He concluded that:

The mathematical axiom that "a straight line is the shortest distance between two points" is thus seen to be an unsafe guide in road making. (4)

Dobson gave distance third priority after the limits of the nature of traffic, and the cost of construction and maintenance. His overall consideration, however, was that of the physical features encountered — mountains, valleys and river crossings. (5) Browne named these "obligatory points", stating that such features as saddles and passes ought to be reviewed at the same time as the towns and settlements to be served by the intended road. (6) Law saw the latter function as the most important and thus deserving of most attention. (7)

Dobson also emphasised the foreseen use of the road as an important factor in the choice of line. For a cart road a gradient of 1 in 9 was sufficient, while for a stock road, steepness was often of little consequence, and it was best to follow watershed lines where practicable, ascending and descending leading spurs and avoiding sideling ground and swampy creeks. He also advocated the consideration of the available means of construction and maintenance, and listed the costs of the road's construction as survey, clearing, surface drains, river crossings, improvement in actual gradients, the formation of road surface, and incidental works such as fencing. He recommended the selection of a line which could be opened immediately and improved gradually. (8) Parnell linked the cost factor with the availability of materials:

It will sometimes happen that road materials can be better obtained by carrying a line of road in one
direction than in another. This is a good reason for making a road deviate from the direct line, because the expense of making and repairing it will much depend on the distances which materials have to be carried. (9)

Browne similarly pointed out that if the road was laid through mountains "where land is of little value" the material for embankments was easily obtainable without having to make cuttings to avoid them. (10)

(b) Specific Guidelines

Mountains and Valleys

Telford's recommendations for the tracing of roads in mountainous areas mainly reiterated the basic principles for the selection of lines:

In a mountainous region, the points to be attended are: (1) the direction and shape of the valleys; (2) the comparative heights of the several passes in the ridges between them; and (3) the obstacles of rivers and sea inlets. (11)

Other theorists concentrated on the achievement of suitable gradients for travellers. Browne's maxim for mountain roads was:

The best line for a mountain road is that on which the total sum of the ascents and of the descents between extreme points is the least. (12)

A related rule was that every possible foot of rise should be gained, never lost. Law advised that the gradient should never exceed 1 in 18, but Dobson recommended 1 in 10 for hilly areas generally while cart roads should be no steeper than 1 in 5. (13) Where the line of road rose steadily, it was suggested that the gradient be broken every 500-600 yards by 100 feet or less of slight counterslope. This was not
only to relieve stock and horses but to break the flow of drainage, since a choked drain could cause great damage on a continuous slope. (14)

The roadmakers agreed that where mountains ridges and valleys were to be traversed, the road which was contoured along the slope was superior to one which was direct. The factors involved in this recommendation were, first, gradient, and second, the cost of constructing the necessary formation for a straight road. Dobson described the alternatives thus:

When the route lies across valleys, as in the case of a road parallel to a coast line passing over the spurs of a coast range ... either the crests of the hills may be cut down and the valleys filled up, to the extent required to obtain a suitable gradient on the most direct line, or the road may be contoured on the hillsides so as to obtain a surface line of greater length with easier gradients. (15)

Like Gillespie (cited above) he concluded that the second course was preferable since it involved less cutting and filling and was thus more economical. Contoured lines were also advisable on sloping ground with long stretches of easy gradient in which case curves should be flattened and spurs cut through (see Fig. 47). Another advantage of contouring a road on surface gradients was that it could be opened immediately and straightened and widened at a later date as funds became available. (16)

Where the ascent or descent was precipitous, Dobson stated that it was necessary, for a practicable gradient, to double the road upon the spurs forming zig-zags. These were to be avoided if a contour line was available, as the expense of the additional lengths required for turning spaces were "very great". (17)

Farnell generally concurred with these points. While a
straight road was, as discussed, highly desirable, "... where hills are high and numerous, it sometimes appears to be advisable to leave the straight line altogether from the beginning in order to cross the ridges at lower levels by a circuitous route". (18) He illustrated his recommendation with a diagram, marking the route A C D (See Fig. 43/2). The ridges could be crossed at less perpendicular height by winding the line of road at lower points.

River Crossings

Dobson regarded unavoidable river crossings as "often the key to the rest of the work". Accordingly, the first step in tracing a line was to determine the location of watercourses and watersheds. Each river crossing was to be examined, the location selected, approaches to bridges carefully set out and the ascents and descents to watersheds contoured. In rock bound valleys the difficulty was in the selection of approaches rather than in the actual siting of the bridge, since "... considerable judgement is often required to avoid dangerous inlines and sharp curves". Dobson criticised the rectilinear system of setting out Crown lands, since "lines of road are made subservient (to it) ... it seldom happens that any thought is given to the proper selection of bridge sites". He outlined three difficulties associated with rivers running between perpendicular cliffs: first, the crossing of the main stream; second, the crossing of lateral streams; and third, the retaining walls required to maintain the width of the road. In general, the crossing of main streams was to be avoided where possible because of the cost involved, but where necessary, the bridges, if of masonry, should be "secured against scour (with the) springing of arches placed above flood level". He recommended that lateral streams be crossed by fords combined with weirs of
timber cribbing, and that retaining walls supporting the river's edge be made of stone. (19)

Parnell wrote with reference to river crossings simply that "the peculiar circumstances of a river may render it necessary to deviate from a direct line in laying out a road". He added that, in general, the cost of a large bridge should be weighed against the distance saved on the road. (20)

Construction Considerations

Most roadmakers stressed that consideration be given to both cost and practicality of the road's construction, thus implying that the surveyor should be familiar with engineering practice. They constantly referred to economy in construction and the avoidance of large-scale formations by deviating the line wherever possible. Law wrote that an obvious principle in arranging the levels of roads was to adjust the cuttings and embankments so that the ground from one could form the other, thus avoiding the cost of transporting materials. (20) Dobson recommended that "... in making out the formation level, cuttings exceeding 10 or 15 feet in depth should as much as possible be avoided". (21) Parnell echoed this advice: "... The most important part of the business of a skillful engineer is to lay out the longitudinal inclinations of a road with the least quantity of cutting and embankment." (22)

As discussed above, zig-zag formations, retaining walls and river crossings were to be considered in terms of their practicality and cost. On a more general level it was considered essential for the road-tracer to examine every possible route so that the best and cheapest could be selected.
Thus, according to nineteenth century roadmakers, the important matter of tracing a road was largely a question of determining a wide range of factors and balancing these against one another to achieve the best possible line. In retrospect their recommendations seem obvious and simplistic, but it must be remembered that the very concept of road planning itself was, in the early nineteenth century, nothing less than revolutionary.
SECTION IV/2/i

BRITISH THEORY : TRACING

Notes

1. Law, p. 23.
4. Ibid., p. 28.
7. Law, p. 23.
11. Telford, p. 207.
15. Dobson, Pioneer Engineering, p. 75.
16. Ibid., p. 77.
17. Ibid., p. 80-81; See also Browne, p. 67.
18. Parnell, p. 48.
20. Parnell, p. 55.
21. Law, pp. 23.
22. Parnell, p. 81.
(ii) Surveying

The survey of roads during the first half of the nineteenth century was undertaken by a number of methods, varying in levels of complexity and precision. The simplest method was the use of the gunter's chain and compass. The chain was composed of 100 links of strong iron wire, each link measuring 7.92 inches, the whole chain measuring 22 yards (or 4 poles) in length. At every ten lengths a piece of brass cut to denote the number of tens was fastened. In addition to the chain, there were ten small iron arrows, or pickets, twenty inches in length, used by:

... the assistant, who has the foremost end of the chain, one of which he sticks into the ground at the end of each chain length; which are collected by the hindermost chain-man or master-measurer. (1)

These arrows were pointed at one end and turned to form a ring at the other. Off-set rods, shod with pointed iron at one end and a small crook at the other, were also used for measuring short distances. These were equal in length to ten links of the chain and divided into ten equal parts. The off-set rod was also used "for ... observing points which are perpendicular to any line". (2)

Crocker gave detailed and lengthy directions for students of surveying in the early nineteenth century:

Having determined on such general lines as are necessary to be measured, and made a sketch thereof in his (the surveyor's) fieldbook, he observes at his first station, the distance, if any, which he is from the fence or boundary of his field and notes the number of links on the proper side of his sketched line ... standing at his first picket (he then) sends his assistant forward to the next picket with the fore end of the chain and one arrow in (each hand) ... who having gone his chain's length as nearly in a straight line as he could guess, ... stands a little to the left, holding his arrow perpendicularly at the end of the chain, and looks
back to the measurer for instructions; whose business it is to direct the chain man's right hand to the one side or the other ... until the arrow be in align with the picket to which he is measuring ... then springing his chain until it lies in a straight line on the ground, he moves his hand downwards as a signal to the leader to stick his arrow in the ground; who (then) proceeds forward another chain's length where he will be enabled readily to bring himself into a proper direction by placing himself in a line with the last arrow and the first picket staff ... thus proceeding until the chain man is arrived at the end of the line when the measurer must count the number of arrows in his hand as so many chains, or hundreds of links, to which he must add the odd links between the last arrow and the picket or end of the line ... (see Plate 1) (3)

If the line to be measured was longer then 10 chains, the procedure was repeated. Boundaries, fences, gates, stiles "or other objects of boundary near which the measurer passes" were measured with the off-set staff and noted as the points to which they were perpendicular. (4) Dobson cautioned that:

... in measuring with the chain, care must be taken to keep it truly level and in passing over rising ground, the handle which is raised from the ground must be carefully plumbed from the arrow below. (5)

The chain was used, as described, in combination with a compass, a plane table, a sextant or a theodolite (see Figs. 137, 138 and 139). The compass could be used to take horizontal angles, but was described by Dobson as "too imperfect for precision". (6) A plane table, which also measured horizontal angles, was defined thus:

... a smooth rectangular board, about 15" by 12" around which is a frame, that not only serves to keep the paper smooth, on which the plan is to be drawn, but, being graduated in degrees, answering to a central point on the board, the angular bearing of any two lines issuing from the station where the instrument is placed may be readily ascertained, or the angle itself may be drawn on the paper. A magnetic needle in a compass box is fixed to one side of the board ... to point out the bearing of any line to the magnetic meridian. There is also a brass index rule, having sundry scales thereon, and also perpendicular sights at the end used herewith. The whole is
supported as a three legged stand and is moveable on a brass ball and socket (see Fig. 139). (7)

The theodolite (see Fig. 137), which measures both vertical and horizontal angles was much more accurate than the instruments so far mentioned. In the early nineteenth century it was a circular instrument made of brass, graduated into degrees on which was an index first for taking horizontal angles surmounted with an arc for vertical angles, and a telescopic sight. It usually had spirit levels to adjust it by and a compass for angular bearings. The instrument was mounted on three legs and a ball and socket, or on a half ball and parallel plates to set it level. (9)

Three types of survey could be undertaken; a survey for a sketch map; a topographic survey; and a geodetic survey. A sketch map could be based on compass bearings and estimated distances rather than on actual measurement. It was checked by observation of the latitude and longitude at principal stations. A topographic survey included not only physical features but also cadastral information and the position of buildings, roads and fences. The geodetic survey was based on the determination of the latitude and longitude of a number of permanent survey points by reference to which every portion of the topographical survey could be plotted correctly. The two methods for this type of survey were triangulation, involving the use of trigonometry to calculate mathematically correct locations, or by meridians and parallels of latitude, or by traverses, both of which were approximations. (10)

Finally, the method by which the levels of the country were ascertained was by use either of a spirit level or a barometer. The latter was found to be more useful since the spirit level required an uninterrupted view of the country. Calculation by the use of the barometer involved the
difference in mercurial height at sea level and at the point of observation but was affected by wind and moisture. The taking of levels was particularly important in the tracing of lines of road, since it provided information about the drainage conditions and the height of principal watersheds. (11)
SECTION IV/2/11

BRITISH THEORY - SURVEYING

Notes

2. Ibid., p. 226.
3. Ibid., p. 227.
4. Ibid., p. 227.
6. Ibid.
11. Ibid.
(iii) Formation - Excavating and Embankment

The formation of a level line was the first and major step in the construction of the road, involving the reduction of the irregularities of the natural terrain by cutting down the high sections and filling in the low (see Fig. 47). It also included the making of a suitable road-bed to receive the material constituting the surface of the road.

Laying out the Road

This initial procedure was described in detail by Law in his Construction of Roads and Streets. After determining the width of the road, stakes were driven in to mark it every chain at the correct distance from a centre stake. Where there was an inclination to be levelled, a strong post was placed on the centre line with a cross piece which indicated the intended height of the formation. For cuttings, pits were sunk correspondingly, depending for height upon the soil and the action of weather and internal moisture on it.

The lines of levels were to be taken at right angles to the original line. In taking these levels the height of all existing roads, rivers, streams or canals were to be noted and benchmarks left on any fixed object at least every half a mile. The exact height was recorded in a level book. The stakes for levels were thus to indicate the planned width, height and depth of the proposed road. They were driven in at equal intervals and a cross section was to be drawn of any deviation.

Soil Types and Road Beds

The stability, and thus success, of roads was recognised as
being dependent upon the nature of the soil and on the

drainage available or provided. Several authors concurred

with Telford’s specifications for road beds on the Holyhead

Road:

Where the ground is nearly level across and neither
cutting or embanking are necessary, the bed for the
metal is to be formed quite level ... In doing this
the natural surface is to be disturbed as little as
possible (see Fig. 67). (3)

Parnell likewise recommended the retention of the natural
surface whenever possible but advocated the building up of the
base for good drainage:

... except where cutting into the surface is wholly
unavoidable ... to elevate the bed with earth two
feet at least above the natural surface of the
adjoining ground (will ensure that) the road will
not be affected by water running under or soaking
into it. (4)

The stability of the road beds depended upon the soil.
Parnell stated that in sandstone country, if the ground was
"solid, hard and uniform" the slopes would stand at 1:1 or
"nearly perpendicular" (see Fig. 43/1). (5) In ground liable
to slip, especially sand and clay, good drainage was the
solution. Law wrote:

... the best preventative is to adopt a system of
thorough drainage, to prevent the surface water of
the ground from running down the side slopes and to
out off all springs which rise towards the roadway
from the side slope. (6)

The road was also to be put at least a foot above flood level,
and where the excavation to form the road bed was great, the
base of the slope was to be increased. (7)

Tomlinson, in dealing with "elastic" soil, by which he
presumably meant slipping or unstable ground, also recommended
both drainage and embankment, adding that a Telford-style
stone base was necessary:

... the elasticity can be destroyed or at least diminished by perfect drainage and other contrivances and by laying a high embankment of earth upon the elastic soil so as to compress it ... it is therefore only by proper drainage and pressure and by making a foundation of large stones in the form of a regular pavement that this elasticity can be effectively diminished. (8)

With regard to embankments made on steep slopes, writers concurred upon the use of a stepped road bed as a base. Farnell recommended that:

In forming embankments along the sides of hills the rule is that the slope to be covered should be cut into level steps to receive the earth, otherwise it will be liable to slip down the hill (see Fig. 43/5). (9)

Both Law and Gillespie echoed this almost exactly, referring to the steps as "off-sets" (see Figs. 49, 51). (10)

Cuttings and Embankments

Telford's specifications for cuttings on the Holyhead Road limited them for the main part to a depth of three feet, with the slopes to be 2 horizontal to 1 perpendicular. He also directed that:

... should hard stone be found in any of the cuttings, the same to be taken out for the use of the road to a depth of at least 6 inches below the surface of the slope, and its place supplied with good vegetable mould. (11)

Farnell also stressed that the slope of a large cutting should never be less than 2 to 1 "except in passing through stone" (see Fig. 43/6-9). (12) With regard to the latter exception, both Law and Gillespie argued that the cutting should still be given an inclination to allow the drying action of the sun and wind "... which is essential in keeping the road surface dry
and in good order". (13) Gillespie also recommended, however, that the slopes be made "... for economy as steep as tenacity will permit". (14)

The correct inclination of the embankments was still more important and in forming them, the side slopes "... should be made with less inclination than that which the earth naturally assumes ... for durability ... and to prevent the width of the surface diminishing by every change in the side slopes" (see Figs. 43/5, 49, 51). (15) Gillespie stated that the variety of slopes possible for embankments usually ranged between 1½ to 1 and 2 to 1, and he gave directives on the actual excavation of material:

Most earth will require to be loosened with ploughs, spades or picks, before being shovelled into the barrow or cart ... for excavation of moderate depths, and for distances within certain limits, barrows are most conveniently employed ... They are wheeled on runs of planks ... laid on the ground or supported on trestles or horses ... The page man does not usually dig, shovel and wheel ... (16)

For longer distances "exceeding the sphere of barrows", horse carts balanced on a pivot for easy tipping could be employed. The materials needed to construct embankments were as far as possible provided by the excavation, but where more earth or stone was required, further side cutting was undertaken.

Where the road was to run along a hillside, most road bulliers agreed that, as Gillespie wrote "... it will be most cheaply formed by making it half in excavation and half in embankment". (17) The embanked portions "are made up from the spurs, care being taken that the upper side of the road shall always be on the upper side of the contour line, so that the surface water may not be penned bank" (see Figs. 47,
Browne recommended that if the hillside was solid rock, the whole road should be cut from it.

A number of methods could be employed to ensure the stability of the embankment. The first was the method of formation itself. Parnell, Gillespie and Law argued that by placing the earth in successive concave layers not more than three or four feet thick, the danger of slips was lessened, since:

If made convex ... and as they are apt to become in the most natural mode of forming them, portions would tend to slip off in the direction of the layers, while the arrangement of concave layers, would resist ... any slip (see Fig. 43/1-4).

Law described a similar though more expensive process. The earth was to be laid in layers of about 4 feet (122 cm) thickness, and each layer well-settled with rammers. It: was best to form the outside of the embankment first and to gradually fill them in towards the centre, so that the earth was arranged in layers, with a dip from the side inwards, again counteracting the tendency to slip outwards.

Telford's final directive for the formation of embankments was that "sufficient time be allowed for the complete consolidation of all embankments before the metal is laid upon them."

**Mountainous Areas**

Where the incline of the slope on which the road was to be constructed was extremely steep, retaining walls were invariably recommended to support the earthen embankment:

In forming a road along the face of a precipice, a wall must be built to support it. The difficulty of forming a road in such a place is not so great as is imagined, for the face of a precipice is seldom perpendicular, and if the inclination should be 1/4
ft perpendicular to one foot horizontal, this will admit a retaining wall being built. (23)

Farnell stated that by building such a wall, thirty feet (9.1 m) high, cutting ten feet (3.05 m) at that height into the rock and filling in the space within the wall, a sufficient breadth could be obtained (see Fig. 43/1). The wall could be made of dry stone where blocks large enough to resist the pressure of the earth could be procured. If the stone was not of sufficient size, hydraulic mortar was to be used (see Figs. 45/3, 50, 52). (24) While blasting could be employed to remove large amounts of rock and earth, it was recommended that a steeper inclination than 1:2 be excavated. (25) When the road crossed ravines, Farnell instructed that the projecting points be cut through and the earth laid across the hollows to maintain the level of the road, rather than building over the natural surface (see Fig. 46/1-2). (26)

The use of zig-zag formations by cutting back and forth across and down a steep slope, thereby reducing the gradient was the subject of some debate. Browne argued initially that they were generally not recommended because they required continual repair, but qualified this by pointing out that it usually happened if the zig-zag had been applied an unsuitable location, where the slope was too steep, the soil "rotten" or where the drainage crossed the road several times. If, however, the side slope was gentle, the soil firm and each reach was drained properly, the amount of maintenance required would be "little more than a straight section". The reaches were not to be shorter than 600 or 700 yards (550-640 m) in length, with a semicircular turning place of no less than 50 feet (15 m) radius, so that the inconvenience was small and danger at a minimum, especially for slow cart traffic. Browne also recommended that paved
short-cuts be provided on zig-zags for flocks of sheep and goats, "... which will otherwise do more damage than any wheeled traffic". (27)

The concerns of road builders with regard to formations thus centred on the stability of both cuttings and embankments, and they emphasised the need for attention to soil types and for the various methods of ensuring solid formations, including stepped bases, concave stratification of earth, adequate drainage and supportive retaining walls.
SECTION IV/2/iii

BRITISH THEORY: FORMATION - EXCAVATION AND EMBANKMENT

Notes

1. Parnell wrote: "In forming a road along the face of a hill that is indented with ravines, in place of carrying the road over the natural surface of the land, the projecting points should be cut through and the earth laid across the hollows so as to straighten the line ..." He illustrated the process in Fig. 43/2, Parnell, p. 83.

2. Law, pp. 29-30.
3. Telford, p. 525.
4. Parnell, pp. 48, 83.
5. Ibid., p. 85.
9. Parnell, p. 84.
12.! Parnell, p. 81.
13. Law, p. 44; Gillespie, p. 55.
15. Law, p. 47.
22. Telford, p. 526; See also Browne, p. 71.
23. Parnell, p. 82.
24. Parnell, p. 82; Law, p. 49; See also Gillespie, p. 169.
25. Law, p. 49.
27. Browne, pp. 67-68; See also Dobson, Pioneer Engineering, p. 80.
(iv) Blasting and Quarrying

Where rock was encountered in the process of making a road, blasting and quarrying were required both to cut the line and to provide material for filling and for any necessary masonry structures. Burgoyne commented in 1868 that the use of gunpowder was the "only modern improvement to quarrying" and that otherwise all tools and methods employed were traditional. (1) According to Andre, it was not until the 1870's that machine drills and electric detonation were introduced into the blasting procedure. (2)

(a) Blasting

As mentioned above, Law recommended that blasting only be utilised where the incline was at least 1:2, and that otherwise excavation and quarrying should be employed. (3) Browne commented that although blasting was slow, tedious and expensive, it had advantages, since:

"... once done, the work may be trusted to give no further trouble. Small changes bring down just what is required leaving the rock solid and free from slides." (4)

Burgoyne wrote that the object generally was to loosen and bring the rock down in large masses, and not to shatter it into fragments. Even for stone of a small gauge, such as road metal, it was better to bring out large masses first and to divide them subsequently either by small blasts with powder or by crowbars and wedges. (5) Andre reiterates these points, and it thus appears that Tomlinson's assertion, that "In the operation of blasting, the blocks are broken irregularly and the stone is wasted" is incorrect. (6) Andre outlined the various steps in the blasting procedure:
The operations of blasting consist in boring suitable holes in the rock to be dislodged, in inserting a charge of some explosive compound into the lower portion of these holes, in filling up ... the remaining portions of the holes with suitable material and in exploding the charge. (7)

The process may thus be divided into three main aspects: boring, loading and firing.

**Boring**

Two simple methods were used to drill the holes to receive the gunpowder - the first using only a jumper and the second using a jumper or drill in combination with a hammer. Gillespie described the first method:

> The holes are drilled by a long iron bar of the hardest steel, chisel-edged, which is raised and let fall on the desired point and at each stroke turned partly round so that the cuts cross each other like the rays of a star. (8)

Andre gave a detailed description and illustration of the jumper (see Fig. 142a). Besides having a chisel-edge at either end, it had a "bead" to give it weight. The bead divided the tool into two unequal portions with the shorter stock used while the hole was shallow, and the longer one to continue it to a greater depth. The blow was obtained by "the direct impact of the falling tool". It was lifted with both hands to a height of a foot and let drop. By this means "... the edge is made to act most favourably in chipping away the rock, and the hole is kept fairly circular". (9)

Where the shot-holes were required in directions other than vertical, the second method of striking the jumper or drill with a hammer (see Fig. 142 f-i) was employed. In this case the jumper did not have a bead, and one end was left flat as a striking face (Fig. 142 b-e). The surface of the rock was
prepared by "striking a few blows with the hammer ... to receive the drill". (10) Andre described the process which followed:

... one man sits down, and placing the shortest drill between his knees, holds it vertically with both hands. The other man ... stands opposite ... strikes the drill ... with the sledge, lightly at first, but more heavily when the tool has fairly entered the rock. One man who holds the drill raises it a little after each blow and turns it partly round, the degree ... usually being 1/8 of a revolution. (11)

To keep the tool cool and to convert dust and chippings to sludge, the hole was kept partially filled with water. When the drill became too short, a longer one was substituted and the first was sent to the smithy for resharpening. The sludge was scraped out with an iron scraper from time to time (see Fig. 143 a-c). (12)

The size of the drill varied between 1 and 3 inches diameter. Generally, the deeper the hole required, the wider the jumper and the slower the boring process, as shown in Table 3. (13) The one-inch drill was used to break the loosened rock into smaller fragments.
TABLE 3: Size of jumpers used for boring holes of various depths in a granite quarry.

<table>
<thead>
<tr>
<th>Jumper Diameter</th>
<th>Depth of Hole</th>
<th>Length Bored Per Day*</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 inches</td>
<td>9-15 feet</td>
<td>4 feet</td>
</tr>
<tr>
<td>2 ½ inches</td>
<td>9-15 feet</td>
<td>5 feet</td>
</tr>
<tr>
<td>2 ¼ inches</td>
<td>5-10 feet</td>
<td>6 feet</td>
</tr>
<tr>
<td>2 inches</td>
<td>4-7 feet</td>
<td>8 feet</td>
</tr>
<tr>
<td>1 ½ inches</td>
<td>2½ -6 feet</td>
<td>12 feet</td>
</tr>
</tbody>
</table>

* By two men striking and one man holding the jumper.

The weight of the hammers used varied with the jumper sizes as Table 4 shows. (14) Boring holes could be undertaken by one man with the use of single handed sets of drills, comprising a set of drills of different lengths and a hammer. Andre however, recommended the use of the double-handed set, by two men because while one man would be "continually obliged to cease for rest", two men could "by repeatedly changing places, keep up ... a succession of blows ...". (15)
TABLE 4: Weight of hammers used with various jumpers.

<table>
<thead>
<tr>
<th>Weight of Hammer</th>
<th>Diameter of Jumper</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 lb</td>
<td>3 inches</td>
</tr>
<tr>
<td>16 lb</td>
<td>$2\frac{1}{2} + 2\frac{1}{2}$ inches</td>
</tr>
<tr>
<td>14 lb</td>
<td>$1\frac{1}{2} + 2$ inches</td>
</tr>
<tr>
<td>5-7 lb</td>
<td>1 inch</td>
</tr>
</tbody>
</table>

Loading

After the hole was drilled to a sufficient depth, it was thoroughly cleaned and dried with a scraper which sometimes had a spiral hook (drag twist) which twisted wisps of hay in the hole and wiped it dry. A piece of rag through a loop in the scraper could serve the same purpose (see Fig. 143 a-c). (16)

The gunpowder was then poured in "... care being taken to prevent the grains from touching and sticking to the sides" in order to avert wastage and premature explosion, and usually filled to 1/3 the length of the hole. If the hole was vertical, the powder could be dropped in, but if on an inclination, it had to be scraped down with an iron scraper. A scoop was used if the hole was horizontal, and if it was inclined upwards, a cartridge was used. (17) The gunpowder used for blasting was evidently of inferior quality and strength to that used for ammunition. It was cheaper but had less rapid ignition, being comprised of nitre (potassium nitrate or salt petre), sulphur and charcoal, of which nitre was the most expensive component. The best gunpowder
contained 75% nitre, while that used for blasting was usually deficient in it and was said often to contain "foul salts". (18)

The next step was to introduce a needle of copper, leading the point well into the charge, and placed against the side of the bore hole. The top of the needle had an eye or handle extending to the outside of the hole. (19) A little wadding of hay, straw or turf was then placed over the powder and the tamping material introduced. The tamping was intended to provide the greatest possible resistance to the charge of powder and was packed as tightly as possible, an inch or two at a time over the powder by the use of a tamping bar or rammer (Fig. 141 d-e). Burgoyne recommended the use of small fragments of quarry stone and dust, or sand, with the last inch or two filled with damp clay. (20) Andre, however, suggested that the whole of the tamping be clay rolled into suitably sized pellets, since "the plasticity of such a pellet enables it to fit all the irregularities of the side of the hole, and to securely seal the passage between the side and the tamping, along which the gasses might otherwise force their way". (21) The tamping bar used to pack the tamping was grooved to receive the needle lying against the side of the bore hole, and flat on the end "to afford a pressing surface for the hand, or a striking face for the hammer". It was usually made of copper or phosphor - bronze to avoid accidental ignition. (22) Andre advised that, close to the charge, "considerable pressure" should be applied, although blows with a hammer should be avoided. Light blows could be applied to the outer tamping to "consolidate the whole". The needle was then carefully pulled out and the circular passage left by it filled with loose, fine-grained powder, or with a series of straws or quills filled with powder. (24) A small piece of touchpaper was then inserted
at the end. Touchpaper was usually made by the quarrymen themselves by soaking coarse paper in a strong solution of gunpowder and then drying it. (25)

Firing

The touchpaper was lit, burned for about half a minute, thus igniting the trail of powder to the charge. Generally, the louder the report from the explosion, "... the less useful effect produced" and fragments of stone were thrown about. (26) Gillespie suggested that these flying fragments could be avoided by placing "any kind of compact bush, such as pine or cedar" on the rocks to be blasted. (27) However, when care had been taken in selecting a correct location and in using the right amount of powder, the sound would be "trifling, and the mass (of rock) will be seen to be lifted and thoroughly fractured, without being forcibly projected". (28)

If there was a misfire, it was extremely dangerous to rebore the hole. If the hole was vertical, or nearly so, the needle hole could be cleaned to allow a thorough wetting of the charge by pouring water down. Sometimes another hole was bored next to the first and the new blast also ignited the old. (29) After the blast the workmen returned to the working face, removed the dislodged rock and broke down every block that had been sufficiently loosened. (30)

(b) Quarrying

Where blasting was inappropriate for the purpose of extracting stone for building, several simple methods of hand quarrying could be employed. Greenwell and Eladen list the most simple technique as the raising of layers of naturally divided
limestone or shale with crowbars sufficiently to enable sling chains to be slipped under them so that they could be lifted out of the quarry by means of a crane. (31)

Tomlinson gave details of a more complex method:

In order to separate a large block, a number of iron wedges (see Fig. 148) are placed in a line a few inches apart on the natural face of the rock and in the direction of the cleaving grain, and they are driven into the stone with heavy sledges until a part is loosened; a channel is then cut in the direction of the length of the intended block, and at a distance equal to its required breadth, the wedges are placed in the channel and driven until the stone is split in that direction also. (See Figs 149, 150.) (32)

Greenwell pointed out that the cleavage produced by the row of wedges in the "chase" or channel, "... usually does not run straight, but takes either an upward or downward direction from face to back". (33) Tomlinson added that, in the case of very hard stone, the wedges were not placed in channels but in pool-holes sunk in the direction in which the block was to be separated from the mass. A similar operation was performed in the direction of the breadth of the stone. (34)

Other quarrying method included guttering, which involved cutting main and cross channels 9 to 12 inches wide and 3 to 4 feet deep with special picks and then detaching the blocks by pinch-bars; and the cutting of main and cross V-shaped channels about 7 inches deep and 3½ to 4 inches wide with a quarry axe and then splitting the stone with wedges and sledge hammers. Greenwell concluded that both these methods were wasteful. (35)

Once large sections of stone were detached they could be split into smaller sections by a method called plug and feather. Shallow holes were drilled about 1½ inches in diameter, 5 or
6 inches deep, in a row 6 inches apart. The boring of these holes involved the use of jumpers or hammers and drills as described above. The feathers were small thin pieces of wrought iron or steel which were rounded off on one side to fit the side of the hole. Two of these were inserted in each hole and the plug, a small wedge of iron or steel inserted between them and driven tight. Each plug was then struck in succession until the rock split (see Fig. 145). (36) The blocks were then reduced to a rectangular form and the irregular parts chipped off with a bevel. (37)
SECTION IV/2/iv

BRITISH THEORY: BLASTING AND QUARRYING

Notes

3. Law, p. 49.
9. Andre, pp. 3-4; see also Burgoyne, Treatise, p. 3.
10. Andre, pp. 4-5, 128.
14. Ibid.
19. Ibid., p. 18; Andre, pp. 43, 133.
24. Burgoyne, Treatise, p. 27; Andre, p. 43.
25. Burgoyne, Treatise, p. 27.
27. Gillespie, p. 165.
35. Greenwell and Eladen, p. 222.
(v) Drainage

(a) Problems

The erosive action of water on roads was one of the major problems to be dealt with by nineteenth century road engineers, and they devised numerous methods of diverting and removing water from the surfaces, as will be discussed. In his explanation of the problems associated with earlier roads, Law maintained that it was the convexity of the formation which caused carriages to keep to the centre, thus forming ruts in which water collected, mud formed and vegetable matter decomposed. The widespread practice of "throwing up" the road, or heaping fresh earth and vegetable matter upon it, did not solve the problem, since ruts soon formed in the same way (see Fig. 64). The road-building revolution concerned itself to a large extent with finding ways to avoid the formation of ruts by making far less convex, durable surfaces in the first place, and by diverting and removing water which caused the rapid deterioration. (1)

The problems of drainage for roads over flat terrain were multiplied for those on hills and mountains. Browne remarked that the "... mere excavation of a wide road along a hillside at once alters the whole system of natural drainage". (2) The water flowed faster and had more erosive power, and roads requiring high embankments and retaining walls were particularly vulnerable. Law stressed the need to keep water off the side slopes and to cut off all springs of water by the formation of ditches and drains. The soil type also affected the type and extent of drainage required. (3)
(b) Drain Types

Drains could perform one or both of two functions - (1) to prevent water from reaching the surface and formation; and (2) to remove water collected on the surface or in the formation.

Side Drains or Gutters

The simplest form of drainage involved the excavation of channels on either side of the road, along its edge, for water off the roads surface and cuttings to drain into. There were no particular specifications for these, but the term usually referred to a drain of fairly shallow proportions. They could pass the water into ditches directly (see Fig. 72) or via culverts (Figs. 44/3, 56 and 73). On a mountain road they were placed only on the uphill side of the road, again to catch water from the adjoining slopes and the surface, and emptied into culverts set at suitable intervals under the road (see Figs. 43-52). Law wrote that side channels were needed in combination with culverts to keep the water off the embankments, preventing them from washing down the gullies. (4) Dobson recommended "shallow paved gutters at intervals to intercept and throw (the water) off" where the gradient was severe, so that the surface water ran along the road's edge instead of across it. He too pointed out that "these gutters should always be on spurs and not on the made embankment" (see Figs. 48-52). (5) Burgoine also referred to the shallowness of side drains:

Where the fall of the ground is rapid, the drain on the upper side of the road will not require to be so deep; all that will be required from it is that it should be sufficient to carry off the surface water of the road ... (6)
Farnell stressed the regular maintenance of side drains in order to keep them open. In the case of hilly ground, culverts were to be placed at least every 50-100 yards (45-91 m) according to the gradient so that the side drains would not be cut by carrying water too far. (7) Browne’s discussion of drainage on steep mountain roads described an elaborate system of large V-shaped drains to be combined with a "secondary" drainage system comprising side-drains, catchwaters and culverts (see Fig. 55). (8) The construction of side drains apparently ranged from the simple excavation of a shallow trough in the earth or stone, to the formation of gutters paved at the base and sometimes at the sides with tiles or stone.

Ditches

Ditches were larger forms of the simple side drains and were often used to empty mitre drains and culverts (see Figs. 67-69, 72, 73). Law wrote that surface water which would otherwise flow over the road could be "cut off by means of a single ditch made on the uphill side of the road to catch and convey water to the most convenient natural watercourse". (5) Spalding recommended that the slope of the ditches should be at least 1½ - 2 horizontal to 1 vertical in order to diminish the erosion of the banks and for the safety of vehicles. (10) Farnell referred to ditches as "main open drains" and specified that, on flat land, they should be 1 foot (30.5 cm) wide at the bottom and 5 feet (152.5 cm) wide at the top (see Figs. 44/3, 61-62). (11)

Covered Drains

These were more sophisticated forms of simple side drains and ditches. They involved more construction and were built in a
wide range of sizes along either or both sides of the road. Law described them as "trenches filled with broken stone" whose function it was to drain water off the wide slopes and convey water into culverts. The covered drain, he wrote, was to be arranged "like an inclined retaining wall, with buttresses at intervals". (12)

Telford's specifications for the Holyhead Road included these specifications for covered drains, calling them "side drains":

The side drain to be sunk 6 inches (152 mm) below the metal bed for the breadth of 14 inches (356 mm) at bottom, and to be filled with stone ... upon which the four inches of gravel is laid, and they are to be finished at a level of nine inches below the level of the driving way (see Fig. 67, cf. Fig. 43/5). (13)

Later in the nineteenth century Spalding called them "porous covered drains" which were to be "readily penetrated by water without becoming clogged by earth washing into them". (14) His designs were similar to those of Law (see Fig. 53). Parnell in 1833 described an even more elaborate type of covered drain which "should run on each side of the road". It was to be constructed of stone or brick in a substantial manner as shown in Fig. 43/10. A flat stone was laid at the bottom of the drain, the side walls were not to be less than 12 inches (304 mm) thick and built in regular level courses. The covering stones were to have a bearing of at least four inches (101 mm) on the side walls. A layer of brushwood was to be laid on top and the remainder of the trench to be filled with gravel or small stones. (15)

Catchwater Drains

Although there was some confusion in terminology, catchwater drains were generally described as being formed obliquely on
the side slopes of the cutting, rather than parallel to the road, and emptied "directly into cross drains" (16) (see Fig. 55). Dobson advised that these should not be placed at the top of the slopes, but at a considerable distance in the rear, leading the surface water to the gullies, thus avoiding saturation. (17) Parnell wrote that catchwater drains were especially necessary in mountainous country, "branching from the upper ends of cross drains in an inclined direction so as to catch the surface water before it can reach the road". (18)

Culverts

Culverts or "cross-drains" were employed to carry the water under the road wherever, as Parnell wrote, "the water would lie on one side of the road and can only be got rid of by carrying it to the other side". (19) They could either pass water into ditches to be carried away, or drain water from ditches, side drains and covered drains. Larger arched culverts could carry small streams under the road, thus performing the function of a bridge (see Fig. 47/11). Parnell wrote that along the slope of a hill or mountain, "... a great number of these are necessary to carry off the water that collects in the channel ... they should be placed at from 50 to 100 yards (45-91 m) distance from each other, according to the declivity of the hill". (20)

Telford's instructions for the Holyhead Road included specifications for eight cross drains of brick laid in lime mortar for every mile:

... each fourteen inches (355 mm) within ... they are to be laid onto solid foundation, with an inclination at bottom of fully one inch (25.4 mm) in every ten feet (3 m) in length and at a depth of 30 inches (76 cm) below the surface of the middle of
the metal bed. The side walls are to be about a foot in height, and the length of a brick in thickness. The bottom to be an inverted arch with bricks set on edge and the curve in the middle to be 2\(\frac{1}{4}\) inches (63 mm); the cover to be an arch with bricks on edge and the rise three and a half inches (89 mm); making the height within at the centre fifteen inches (38.1 cm) (see Figs. 59, 70). (21)

These cross drains were to be continued under the fences into the ditches on each side (see Fig. 70), and when they passed under embankments, they were to be "firmly backed with earth well-rammed, and covered with good turf; above this to the metal bed, good earth is to be laid and well rammed". (22)

Such specifications for the size, frequency and construction were however, as Spalding wrote, dependent on a number of factors, such as the maximum flow of water likely, the position of the road in relation to streams, the character of the surface and soils, and the nature of the side-channels provided. (23)

Regarding firstly the recommended size of culverts, earlier roadmakers such as Telford and Parnell specified widths of 14 inches and 18 inches respectively (see Figs. 45/5 and 59), while later writers generally recommended larger culverts. (24) Law wrote that they should be "of sufficient size to carry large volumes of water and to admit a man to pass through them so that they may be cleared out and repaired without breaking up the roadway". (25) Spalding recommended a minimum size of 18 x 24 inches (457 x 609 mm) for the same reasons (see Fig. 57). Culverts were commonly built between 2 and 4 feet (61 and 122 cm) in width and 2 and 5 feet (61 and 152.5 cm) in height. (26) Referring to culverts built on steep mountain roads in India, Browne wrote:

There can be no greater mistake than, for reasons of economy, to construct small drains of any kind for mountain roads in tropical climates, as they are
certain to choke up in the first shower. Cross drains, if provided with a moveable slab top (should be no less than 2 feet by 2 ½ feet (61 and 76 cm), or, if permanently covered in, (no) less than 2 feet 3 inches by 2 feet 9 inches (68.5 by 83.8 cm). (28) Thus the emphasis was again on the need for access for future maintenance.

Secondly, regarding the frequency of culverts, Telford specified eight cross-drains per mile or one every 220 yards (201 m), while Parnell recommended one every 50-100 yards (45-91 m) on hilly ground. (29) Browne wrote that in very rainy districts such as Kangra in India, "... one (culvert) was provided every 120 feet (36.5 m), while in drier localities 1 in every 300 feet (91 m) was sufficient". (30)

Thirdly, regarding construction, culverts could be built of stone, brick or wood, while later in the nineteenth century pipes were used. Gillespie gave details of the basic box culvert, echoing Telford's specifications with regard to the concave, inclined base:

Their simplest form consists of two walls of stone or brick covered in with slabs and having a foundation either of wood or stone, laid in the form of an inverted arch ... Their bottoms should be inclined 1 in 120 or 1 inch in 10 feet (25.4 mm in 3050 mm) (cf. Fig. 57). (31)

Parnell's directives on masonry culverts were more detailed. The side walls were to be 16 inches (406 mm) thick, faced on both sides, 18 inches (457 mm) high at the upper end and 23 inches (584 mm) at the lower end, resulting in a slope which allowed water to run freely through the culvert. The top of the walls were to be level, and the bottom of the culvert was thus to have, as Telford had recommended, an inclination of one inch every ten feet. The stones at the top of the side walls were to project about 2 ½ inches (63 mm) over the side.
walls, forming head walls, and the coverstones were to be at least 4 inches (101 mm) thick and 27 inches (685 mm) long, neatly jointed, closely laid together and properly bonded to the side walls. The base of the culvert was again to be concave with the stone no less than 5 inches (127 mm) deep (see Fig. 45/5). The ends of the culvert were to be paved, with the "... paving stones below the discharging end ... of large stones sunk so deep as to secure the whole from being injured by the current of water". (32) The latter recommendation was identical to that originally made by Telford and was later echoed by Gillespie. (33) Where the culvert was connected with a natural watercourse, both ends were to be secured by wing walls at least five feet (252 cm) long. Gillespie pointed out that these were to have an "outward and downward slope corresponding with that of the embankment". (34) On Browne's mountain roads the outlets of culverts were incorporated into retaining walls and were covered in by slabs of between 2\(\frac{1}{2}\) feet and 3 feet (76 and 91 cm) span. For long spans (up to 10 feet/305 cm) "a rubble stone arch, built of picked stones neatly mounted and wedged up is, whilst much cheaper, quite as strong and reliable as arching in mortar". (36)

Both Telford and Farnell provided instructions for the construction of inlets or side openings by which water from the side drain was passed into the culvert. Telford, again specifying brick in lime mortar and stone as materials, directed them to be:

... ten inches by 14 inches (254 x 355 mm) in the clear. The side and back walls ... to be raised four inches (101 mm) above the side drains, and the front wall to be kept a little lower than the said side drains. They are to be covered with good sound stone, at least 24 inches long, 1½ inches broad and two and a half inches thick (609 x 355 x 63 mm) ... the water to be introduced by a row of paving stones. (see Fig. 70) (36)
Parnell described the same type of inlet on a slightly larger scale - they were to measure 10 inches by 16 inches (254 x 406 mm), with the covering flags 26 inches long, 16 inches broad and 2 inches thick (660 x 406 x 63 mm), standing six inches (152 mm) above the level of the side drain (see Fig. 45/6). (37)

Most writers reiterated the recommendation that the culvert should have an inclined base to "... insure (sic) proper scouring and an easy change of direction for the water" (see Figs. 48 and 50), as Browne explained. He advised that a slope of 1 in 12 was suitable and that the culvert itself should be built at an angle of 135° to the side drain. Gillespie also recommended that culverts be made to cross the road obliquely (see Fig. 55). (38)

Finally, a cheaper alternative to stone and/or brick culverts was the wooden culvert. Spalding wrote that these could be easily constructed of planks or heavy timbers, but recommended their avoidance, "... on account of (their) perishable nature and lack of economy". (39) In Dotson's view, however, they were desirable because of their short-term economy. He described them as comprising:

... logs roughly squared and of sufficient size and weight to keep their position without either bolts or dowells. The floor should be made of stout poles laid across the road so that carriage wheels may not fall in between them (see Fig. 58). (40)

He added that the whole structure should be covered with sheets of bark and a layer of loam and metal.
Mitre Drains/Trenches

Although constructed in a similar fashion to covered drains, mitre drains or trenches were placed across and under the road surface rather than alongside it. (41) The directives provided varied from one writer to another - Telford ordered them to be made "... 12 inches (304 mm) wide and 6 inches (152 mm) deep below the metal to be made from the middle of the road with proper declivities into the side drains ... one for every 60 yards (54.8 m) in the length of the road; they are to be filled with stones" (see Figs. 68 and 69). (42) Parnell described a deeper, angled mitre drain with sloped sides, measuring 9 inches (228 mm) width at base, 12 inches (304 mm) width at top and 10 inches (254 mm) depth. He added that the angle or splay of the drain was dependent on the inclination of the road, and that the slope of the drain itself was not to exceed 1 in 100, otherwise running water would injure the sides (see Figs. 61-63). (43)

Law in the 1880's categorised these drains as "underdrainage", and where they were not angled, called them "trenches", describing their construction thus:

When the surface of the ground is formed to the level intended for the reception of road materials, trenches should be cut across the road from a foot to 18 inches (304-457 mm) in depth and about a foot wide at the bottom, the sides being sloped ... a drain of not less than 4 inches (101 mm) square internally should be formed in the trenches of old bricks, drain tiles or flat stones and the remainder of the trench filled with course stones free of clay and dirt ... these drains must have a fall from the centre of the road into the ditches on each side, 1 in 30 is sufficient. (see Fig. 54) (44)

For wet ground he recommended one of these trenches every 20 feet (6.1 m), with fewer for firmer, drier ground. Apart from the drain at the base and the larger dimensions, the
description matches that of Parnell. Law also mentioned their
construction in the form of a flat 'V', with the apex in the
middle of the road, draining roads on inclined ground (see
Fig. 56). (45)

Central Drains

Channels cut or constructed down the centre of the road
alignment are scarcely mentioned in the books of nineteenth
century road builders. Dobson alone shows such a drain in a
diagram of a road excavated on both sides from strata of
limestone, shale and clay (see Fig. 60). In this case, a
small pipe-like channel with a curved cover is located beneath
the surface formation. No information is given as to whether
this drain was gravel-filled or how it was drained. (46)
SECTION IV/2/x

BRITISH THEORY : DRAINAGE

Notes

1. Law, pp. 1-6.
2. Browne, p. 79.
3. Law, p. 45.
4. Ibid.
5. Dobson, Pioneer Engineering, pp. 103-104.
7. Parnell, pp. 96, 98.
9. Law, p. 45.
11. Parnell, p. 95.
12. Law, p. 46.
15. Parnell, p. 95.
16. Law, p. 48; see also Browne, p. 79 ff.
17. Dobson, Pioneer Engineering, pp. 103-104.
18. Parnell, p. 96.
19. Ibid.
20. Ibid.
22. Ibid.
23. Spalding, p. 31 ff.
24. Parnell, p. 96; Telford, p. 526.
25. Law, p. 48.
27. Ibid.
29. Telford, p. 526; Parnell, p. 96.
30. Browne, p. 79 ff.
32. Parnell, pp. 204-205.
33. Telford, p. 526; Gillespie, p. 178.
34. Parnell, p. 205; Gillespie, p. 178.
35. Browne, p. 79 ff.
37. Parnell, p. 205.
38. Browne, p. 79 ff; Gillespie, p. 178.
41. Forbes, p. 536; Telford, p. 526.
42. Telford, p. 526.
43. Parnell, p. 95.
44. Law, p. 76.
45. Ibid.
(vi) Pavements

(a) Problems

The construction of durable pavements was the facet of road-building which preoccupied most nineteenth century road engineers, since the poor quality of earlier road surfaces had resulted in thoroughfares which were continually impassable and in need of repair. The problems to be overcome by proper pavements were for the main part the same as those related to drainage. On earlier English roads, the surfaces had been made as convex as possible in the belief that this would drain the road adequately. Soft materials such as earth and vegetation were heaped up about the centre with the result that the sides became dangerous and carriages followed the central course. Ruts quickly formed, collected water and converted the material into mud. The indented road was then "barrelled" with more "clods and rushes, soft soil and other material" and the whole process recurred, as illustrated in Fig. 64. (1)

(b) Development of Road Surfaces in Europe

The movement towards "scientifically" formed pavements apparently began much earlier on the continent than in England, though it had had a more gradual development. Forbes traces its evolution back to the well-designed roads for cities of Andreas Palladio (1518-80) and several of his contemporaries, many of whom were inspired by the remains of the ancient Roman roads. In France, the work of Gautier (1660-1737), the engineer of the Corps des Ponts et Chaussées (est. 1716), included a "road-body enclosed by stone walls and built from earth and hard core, well-rammed before traffic was admitted". Nicholas Bergier, a Rheims Lawyer (1567-1623),
had earlier compiled information on the remains of Roman roads and published the results on his *Histoire des Grand Chemins de l'Empire Romain.* (2) During the first half of the eighteenth century roads in France were built according to the principles of Bergier and Gautier. A road trench was dug 18 feet (5.5 m) wide and two or more layers of stone were laid flat by hand at the base. A layer of small stones was placed and rammed down over this and the wearing surface was formed by a coat of stones broken smaller then those immediately beneath. The depth of this causeway was 18 inches (457 mm) at the middle and 12 inches (304 mm) at the sides (see Fig. 66a). Forbes maintains that this type of construction was introduced in numerous other European countries. About 1775 a new system devised by Pierre Tresaguet (1716-1794) was introduced in France. Tresaguet was critical of the lack of attention paid to the level and drainage of the subsoil water and the unevenness of the stone and rubble employed. He disapproved of the foundation which did not run parallel to the surface and which was thus so deep in the centre as to be wasteful. He advocated the reduction in the thickness of the road-bed to 9-10 inches (228-254 mm), thus lowering the cost of the to less than one-half. His directives for the road's construction were as follows:

... the bottom of the foundation is to be made parallel to the surface of the road. The first bed of the foundation is to be placed on edge, and not on the flat, in the form of a rough pavement, and consolidated by beating with a large hammer ... The second bed is to be likewise arranged by hand, layer by layer, and beaten and broken coarsely with a large hammer, so that the stones may wedge together and no empty space remains. The last bed, 3 inches (76 mm) thick, to be of pieces broken to the size of a small walnut ... and thrown upon the road with a shovel to form a curved surface ... (see Fig. 66b).

His pavements were much less convex and thus less dangerous, yet still allowed proper drainage of the road. He maintained
that "in Limoges such roads lasted for ten years when constantly maintained and ... they were as good as when first constructed". It was Tresaguэт's method which was later adopted by Telford and modified by MacAdam. (3)

(c) Telford and MacAdam

The resistance of carriages upon roads has of late years been very much diminished by covering the surface with materials broken into smaller pieces than formerly; thereby forming a much smoother surface ... such a surface is much more easily kept in repair than the rough uneven roads previously in existence. The public is indebted to Mr. MacAdam for the introduction of this system, ... but the late Mr. Telford ... has contributed more largely than any other person to our stock of information of road making, and which may all be summed up in one simple rule viz "that a good foundation is the first requisite". (4)

Nicholas Wood in 1838 thus summed up the popular view of the two famous engineers and the contemporary debate amongst road builders concerning their respective methods.

Thomas Telford (1757-1834) was originally a journeyman stonemason whose wide experience in road building was gained in Shropshire and in the reconstruction of General Wade's roads in Scotland. He gained most recognition by his work on the London-Holyhead Road between Shrewsbury and Holyhead. (5)

For the pavement and its base he devised a system similar to that of Tresaguэт, directing it to be constructed 30 feet (9.4 m) wide with a causeway of 18 feet (5.4 m) in the centre:

A bed for the metal to be formed ... (quite level; ... a bottom course or layer of stone is to be set seven inches (177 mm) deep in the middle and five inches (127 mm) deep at the sides. The stones to be the full depth of the bed, to be the hardest and most durable ... They are to be neatly set by hand in the form of a close firm pavement ... all the inequalities of the upper part of the pavement to be broken off by the hammer ... (see Fig. 67). (6)

Telford's method differed from Tresaguэт's in the next step,
which was the filling of all the interstices with stone chips "firmly packed by hand". The foundation was to form a "regular convexity of two inches (50 mm) in the breadth of eighteen feet (5.4 m)". Thus the convexity was provided by this stone course rather than by the curved earth base of Tresaguet's design (cf. Figs. 66 and 67). For the next course:

... (the) stones to be broken into pieces as nearly cubic as possible, so that the extreme points of every stone may pass through a ring of 24 inches (63 mm), and that none shall exceed the weight of 6 oz. The depth of the said broken motal bed when consolidated to be six inches (152 mm), and breadth 18 feet (5.4 m) (see Fig. 67). (7)

A third layer comprising one and a half inches (38 mm) of "good binding gravel" was then laid to complete the pavement (see Fig. 67). Telford added that "when this work is properly executed, no stone can move".

In his evidence before the Select Committee of the House of Commons in 1818, Telford emphasised the need for drainage, minimum convexity of the surface and the avoidance of steep gradient by the formation of cuttings and embankments. (8) During the 1820's he also drew attention to the current problems of street pavements in his "Report Respecting the Street Pavements etc. of the Parish of St. Georges, Hanover Square" (1824). For these he recommended a different construction method, consisting of a bottoming of broken stone 12 inches (304 mm) deep upon which an ashler causeway of evenly sized and shaped granite blocks was formed (see Fig. 44/1-2). (9)

While they were widely acclaimed, Telford's roads were also expensive as a result of the handset foundation. A cheaper alternative was devised by John Loudon MacAdam of Ayer
MacAdam conducted numerous experiments during the late eighteenth century and became Surveyor-General of the Bristol Road Trust in 1815. (10) His theories differed radically from Telford's in that he believed that the expensive handset foundation of large stones could be dispensed with altogether, since:

... it is the native soil which really supports the weight of traffic; ... while it is preserved in a dry state, it will carry any weight without sinking and ... it does in fact carry the weight of roads and carriages also ... (11)

The key to the success of this theory was the maintenance of the road in a completely dry state:

... this native soil must be previously made quite dry, and a covering impervious to rain must be placed over it in that dry state ... (12)

The first step in forming a completely dry road was thus "the reverse of digging a trench". The road was to be raised above the adjacent ground so that there was a sufficient fall to take off water. Drains could be made to lower ground or, if not practicable, the "soil upon which the road is to be laid must be raised some inches above the level of the water". (13) MacAdam maintained that the pavement of broken angular and graded stone chips could be as little as 10 inches (254 mm) thick, (see Fig. 71), but he provided no rigid rules for thickness such as those given by Telford. The thickness of the road "should only be regulated by the quantity of material necessary to form such impervious covering and never by any reference to its own power of carrying weight". (18) He outlined the method of forming such a surface:

Having secured the soil from under water, the road maker is next to secure it from rain water, by a solid road of clean dry stone, or flint, so selected, prepared and laid as to be impervious to water; and this cannot be effected unless the
greatest care be taken that no earth, clay, chalk or other matter that will hold water be mixed with the broken stone; which must be so laid as to unite by its own angles into a firm compact impenetrable body. (15)

The stones were to be carefully graded by the use of the 2 inch gauge ring (see Fig. 152d) and no stone was to weigh more than 6 oz. The metal was to be laid in thin layers in three stages, with time allowed between each application for consolidation by traffic. MacAdam also advocated the use of existing materials in the case of old roads, by breaking up the large stones forming them, and he also stressed economy in road building, and in the administration of finances. (16)

Like Telford, MacAdam sought to keep the road as level as possible and to avoid steep gradients, which played havoc with the essential drainage systems. However, where Telford had specified a slightly convex surface, MacAdam recommended that its cross-section be formed of two straight lines inclined at the rate of 1 in 30 and connected at the crown or middle of the road by a segment of a circle having a radius of about 90 feet (see Figs. 71 and 74). (17) He believed that it was the convexity of old roads which had caused their problems:

I consider a road should be as flat as possible with regard to allowing the water to run off it at all, because a carriage ought to stand upright in travelling ... I have generally made roads 3 inches (228 mm) higher in the centre than I have at the sides ... if the road be smooth and well made, the water will run off very easy to such a slope ... when a road is flat people will not follow the middle of it as they do when it is extremely convex. (18)

Although they agreed on the need for solid surfaces of carefully graded stones, proper drainage, and the evils of extremely convex surfaces, the theories of the "rival road builders" differed radically, with the argument revolving
about the function of the pavement and its foundation. The debate was perpetuated throughout the nineteenth century by a succession of road builders, taking one or the other view and usually focusing on the presence or absence of a heavy base of stone pavement. However, it was the actual function of the pavement which was in question. In Telford’s view the pavement with a heavy foundation was necessary to bear the weight of traffic, while to MacAdam the relatively thin pavement was simply there to keep water from penetrating the natural ground, which was the true carrier of traffic.

(d) Usage

Before any construction was undertaken, most road builders tried to ascertain the likely nature and amount of traffic which would use the road. Telford recommended that this factor be taken into account when selecting the type of surface to be formed, for reason of economy, and suggested various “classes” of roads of different quality. (19) Parnell’s diagram (see Fig. 44/1-4) illustrates this range, and he reiterated Telford’s advice, writing that the consideration of future usage should determine its type. Heavily used roads needed a “proper degree of strength” and the regular foundation of large stones. (20) Dobson’s emphasis on economy in road building led him to make the “limits of the nature of the traffic” the first priority in laying out the road, (21) and Tomlinson provided a list of road types in order of their importance:

1. A road of earth put into a regular form
2. A road of gravel laid in natural soil
3. A road with broken stones laid on natural soil
4. A road with a foundation of rubble stones and a surface of broken stones or gravel
5. A road with a foundation of pavement and a surface of broken stone
6. A road of which the surface is partly paved and partly made into broken stone or other material
7. Paved roads (22)

As an advocate of Telford's techniques, he placed Macadam's method, the "road with broken stones laid on natural soil", near the bottom of the list.

Law added that the cost of maintaining a road did not entirely depend on its extent and width, but more on the nature and amount of traffic. A heavily used narrow road, he wrote, would be worn out more quickly than if it had been made wider. (23) Gillespie wrote that the minimum width of a road was one rod, or "sufficient to enable two vehicles to pass each other with ease". A width of 30 feet (9.1 m) was "fully sufficient for any road, except one which forms the approach to a very populous city". He added that in England the limits of the width of by-roads were 20 feet (6.1 m) for carriage roads and 8 feet (2.4 m) for horse roads. (24)

(e) Construction

It appears that Telford was partly inspired by an earlier road builder, John Metcalfe of Knaresborough who, like the French road builders, had studied the old Roman roads and had reused stone from them to build new roads in the second half of the eighteenth century. He also devised the corduroy road, comprising a surface of logs or planks laid perpendicular to the alignment of the road and sometimes paved with gravel which was particularly suitable in muddy, marshy conditions. (25)

Most nineteenth century road builders subscribed to either the Telford or the MacAdam system and there was a tendency for theorists writing about countries other than Britain to favour the latter, while in Britain, where roads were of less extent
... already established, they adhered to the former, stressing in particular the necessity of the solid base.

Forbes maintains that most of Telford’s contemporaries did not like his use of the final layer of gravel which, "by sinking between the stone (beneath) diminishes the absolute solici ties to the surface of the road lets in frost and contributes to preventing complete consolidation of the mass of broken stone". If not properly maintained, the top layers of Telford’s roads "... proved too thin for the wear of traffic ..." (26) Farnell was one of those who eliminated the uppermost layer of gravel from his specifications. (27)

The major drawback of Telford’s heavy construction was the expense of the foundation. MacAdam, on the other hand, stressed economy of materials and labour. His 1819 directives for the repair of an old road specified that no additional material was to be used, unless the stone already present was not ten inches thick. The stone was to be loosened and broken, no piece to exceed 6 oz in weight and the road laid as flat as possible - a three inch rise from the centre to side was sufficient for a road 30 feet (9.1 m) wide. The old stones were to be gathered with a strong heavy rake with teeth 2 1/4 inches (63 mm) in length (see Fig. 152/f) and broken with hammers (see Fig. 152 b, c) by men seated at the side of the road. The road was then raked smooth and, as soon as it was prepared, the stones were to be scattered rather than shovelled upon it. He directed that "only a small ... be lifted at once; five men in a gang should be sent to lift it all across, two men should continue to pick up and rake off large stones and form the road and the other three should break stones". (28)

Regarding the consolidation of the layers of stone by traffic,
Tomlinson suggested that "guards or fenders" be placed on the road "... as to make the carriages pass over every part of its surface in turn. Unless these precautions be observed the road will never become firm". (29) Gillespie reported that to save costs it was common practice to metal only the central causeway and to form the sides or "wings" of natural earth "... 16 feet (4.8 m), for the middle and twelve for the sides is a common proportion". (30) It is unclear whether or not MacAdam himself practiced this, although it appears unlikely, given his principle that the function of the pavement was to protect the natural surface from water. His directives as cited above imply that stone was scattered over the whole width of thirty feet (9.1 m). The causeway with its earthen wings as described by Gillespie had been adopted by Telford, (see Fig. 67) who instructed that the "sides of the metal be shouldered within four inches of the finished surface with good mould". (31)

A version of MacAdam's methods was also recommended by Dobson in 1877, particularly for new colonies and for extensive and rough terrain. The stone was to be broken by hand and, in contrast to MacAdam's method, was to be graduated in size from the foundation to the surface. He also advised that the metal should be blinded with sand or fine gravel rather than mud. (32) The practice of washing sharp sand into the uppermost layer had already been devised by one of MacAdam's predecessors, Richard Edgeworth (1744-1817) but was condemned by MacAdam himself. (33)

Gillespie also included details of a corduroy road based on Metcalfe's design:
rapidly made passable by filling a sufficient number of young trees as straight and as uniform in size as possible and laying them side by side across the road at right angles to its length. (see Fig. 75) (38)

Dobson regarded these surfaces as a temporary measure only. He gave instructions for the construction of a slightly different type:

Cut the saplings as nearly as possible of the same thickness and use none shorter than the width of the intended road. Lay down not less than three rows of stringers viz one at the centre and two at the outside. These should be made of half-round split timber; and as the saplings are laid put another tier of stringers above them, and treenail them to the lower tier. (39)

Although, as Gillespie wrote, these surfaces were "very unpleasant to persons riding over it", they were, he concluded, a "very valuable substitute for a swamp".

(f) Maintenance

The key to the success of these carefully constructed road pavements was continuous and thorough maintenance. Macdadam's broken stone formation was to be kept even and clean by the addition of proper fresh materials immediately after rain in order that the new materials might "bind and incorporate properly with the old". Ruts were to be filled with fresh metal as soon as they appeared, since any irregularity would quickly lead to the disintegration of the pavement. (40) Burgoyne thus enumerated two methods of maintenance; first, "to keep the road perfectly clear of dust, dirt or unconnected matter over the crust of the consolidated broken stone" and second, "that minute repairs (be made) to the surface in small patches immediately on the appearance of any want of form of substance". The mud and dirt could be removed by various scrapers or blunt shovels and birch brooms when a hole or rut
was forming, the pavement around the hollow was to be loosened with a pick, filled and firmly rammed with a mallet. (41)
(See Fig. 152 a-c).
SECTION IV/2

BRITISH THEORY: PAVEMENTS

Notes

1. Law, pp. 1-6; MacAdam, Remarks on the Present System of Road Making, p. 11; Telford, p. xv.
3. Ibid., pp. 527-528.
5. Telford, p. 2; Fleming and Brooklehurst, p. 81; Forbes, pp. 531-532.
7. Ibid.
10. Law, p. 7; Fleming and Brooklehurst, p. 81; Forbes, p. 532.
12. Ibid.
15. Ibid., p. 534.
16. Ibid.; Law, p. 9; MacAdam, Remarks on the Present System of Road Making, p. 34 ff.
17. Telford, p. 526; MacAdam, Remarks on the Present System of Road Making, p. 34; MacAdam cited in Law, p. 69.
20. Parnell, p. 61.
23. Law, p. 68.
25. Fleming and Brooklehurst, p. 81; Newell, p. 43.
26. Forbes, p. 532; see also Gillespie, p. 201.
27. Parnell, p. 70.
30. Gillespie, p. 47.
35. Parnell, p. 48.
37. Gillespie, p. 49.
40. MacAdam, *Remarks on the Present System of Road Making*, p. 34.
(vii) Retaining and Breast Walls

1. Function

Where the terrain was particularly steep, large embankments were often enclosed by retaining walls. Dobson defines them thus:

The name retaining wall is applied generally to all walls built to support a mass of earth in an upright or nearly upright position, but the term is, strictly speaking, restricted to walls built to retain an artificial bank. (1)

Breast walls, on the other hand, were those walls which protected and "sustained the face of solid ground". They were thus constructed on cuttings made through unstable ground or ground subject to erosion. (2) Law wrote similarly that retaining walls of dry stone could be constructed against the embankment for "... durability and to prevent the width of the surface diminishing with every change in the side slope", and that, on steep slopes, where embanking alone was insufficient, retaining walls and breast walls were necessary for embankments and cuttings respectively. (3)

2. Masonry

(a) Types

Masonry of widely varying quality and cost could be used for retaining walls. Dobson, describing mortared walls, categorised them into three types - ashlar, block-in-course and rubble work (see Fig. 76). The first, ashlar, required that "... all the surfaces (be) taken out of winding and the abutted surfaces worked to planes with greater or lesser finish, according to the intended thickness of the mortar
joint". The second type, block-in-course, was similar in that the face and beds were taken out of winding, but the joints were squared a short distance from the face while the backs were left rough. The beds were not squared and the vertical joints were packed with spalls. For the third type, rubble work, the stone received "no dressing, beyond what was given with a spalling hammer, to take off the sharp points and to give the work a face". Bobson also subdivided the rubble work into three categories: 1. Stones of any shape except round pebbles bedded in a mass of mortar, thus forming a species of concrete; 2. Large long stones, laid as headers overlapping each other, the interstices filled up with smaller stones; 3. Flat bedded stones roughly squared on the beds with the spalling hammer, set in courses. (4)

Tomlinson's Cyclopaedia also included a similar, though simplified, typology, again dividing masonry into three categories:

- **Rubble Work**: in which the stones are used without being squared.
- **Coursed Work**: in which the stones are squared more or less, sorted into sizes and ranged in course.
- **Ashlar Work**: in which each stone is squared and dressed to given dimensions (see Fig. 76). (5)

The type of walls constructed in a given case depended upon its required height, the steepness of the hillside, the size and height of the embankment, and the resources, skills and materials available. The roadmakers recommended differing styles and standards for various roads they described.

(b) Construction

The degree and nature of the dressing of stone blocks depended upon the type of wall intended. For ashlar work, a plane surface was made on one of the largest sides of the block,
which generally formed one of the beds. The required shape was then marked on this surface, either with a square or templet, chisel drafts were sunk across the ends of one of the adjacent faces by means of a square or bevel and this second face was worked between these drafts. The position of the third side was then determined and its face worked in the same manner. The process was repeated until the block was of the required shape and proportions (see Fig. 77). (6) In the case of harder and more coarsely grained stone, the surfaces were generally tooled, meaning that the marks of the chisel were left on the faces. If these marks were regularly arranged the work was described as "fair faced", but irregular markings were referred to as random-tooled, chiselled, beasted or pointed. (7) If the wall was to be of rubble work, the block was roughly brought to shape by a stone axe, also known as a jedding axe, slobbering hammer, or cavil. (8)

While Telford specified that the walls on the Holyhead Road be mortared, (9) and Dobson described only mortared walls, other writers advocated dry walling wherever stone blocks of large dimensions were available. Browne cited as an example the wing walls of a bridge in India "... 350 feet in length, 70 feet in height and built of split granite boulders lain perfectly dry". (10) Law also suggested dry walling with large blocks, while small blocks could be used if laid in hydraulic mortar. (11) While mortar was necessary to bind an upright wall built in horizontal courses, it could be dispensed with in the case of retaining walls by the battering or sloping of the face. In the latter case, according to Dobson, the use of mortar would be only an "additional security" against slippage. (12) Another advantage of the dry-laid wall was that while mortar could take several months to become thoroughly set, thus delaying the filling of the embankment, the cheaper dry walling could be filled
Both MacAdam and Telford paid little attention to the construction of walls, although Telford did include specifications for them, where necessary, on the Holyhead Road:

Across the hollow there is to be a wall built in good lime mortar along the foot of the lower slope of the present road, or 30 feet (9.1 m) distant from the (breast) wall. This ... wall is to be 2 feet (76.2 mm) thick at top and to increase downwards at the rate of 2½ inches (63 mm) for every foot (305 mm) in depth, by a regular batter on the outside. There is to be a four feet (1.2 m) parapet wall on the top 2 feet (61 cm) thick at the bottom and 18 inches (45 cm) at the top ... (10)

Parnell included an illustration of such a wall in Fig. 46/3. Telford thus gave dimensions for the batter and included a parapet wall, but did not mention guidelines for foundation or embankment construction. Subsequent road builders, by contrast, stressed the necessity for strong and solid foundations. Browne wrote that sandstone was totally unsuitable for wall foundations in tropical climates, since if unexposed to air below ground level, it would disintegrate—"Retaining walls of what seemed most compact sandstone have suddenly collapsed, the underground courses having dissolved to sand". (15) He therefore advised that foundation be built of split granite boulders. Rock or clay was to be chiselled or blasted out into steps vertical to the proposed front slope of the wall. The foot of the wall was to be protected by boulder pitching extending outward from five feet to 20 feet (1.5 - 6.1 m), (see Fig. 50), and the water from culvert was to be thrown well-clear by wooden troughs or stone slabbing. (16)
Dobson also recommended that the foundation of the wall be "bench'd out" (see Fig. 79) or cut into steps. He wrote that the two causes of foundation failure were firstly inequality in the settlement of the ground, and secondly lateral escape of supporting materials. Benching, by providing a level base for the wall, obviated these problems. He suggested also that foundations be brought up to a uniform level with large blocks of stone. A natural solid stone shelf was the best foundation but, where not available, the ground was to be uniformly yielding rather than unyielding. (17)

The road builders invariably recommended that the face of the wall be battered. Dobson discussed a range of possible shapes and necessary size in the case of an embankment 12 feet high (see Fig. 78). While an upright wall with horizontal courses required mortar, as discussed, as the "chief resistance to sliding", the triangular shape, with a battered face, provide increased leverage for supporting the mass of earth behind it, and also provided resistance to the courses sliding over each other. (18) The recommended dimensions of retaining walls were usually given in terms of the rate of batter, increasing the depth of the wall in relation to its height. Dobson wrote that, generally, the base of the wall should not be less than \( \frac{1}{4} \) its vertical height. (19) Telford, as cited, specified a batter of 2 \( \frac{1}{2} \) inches in every foot, while Browne recommended that all retaining walls, regardless of their height, were to be 2 foot 3 inches (685 mm) thick at the top, with a batter of 1 in 4 on the outside (3 inches per foot) and 1 in 8 (1 \( \frac{1}{8} \) inches per foot) on the inside. (20) Gillespie maintained that the "batir" could range between 1/24 (\( \frac{1}{2} \) inch per foot) to 1/8 or 2 inches in a foot. (21)

The use of buttresses to strengthen walls and reduce their requisite size was briefly mentioned by some road builders,
but their construction and proportions were not dealt with. Counterforts, built on the inside of the wall were also referred to, but were apparently unsuitable, as they were "frequently torn from (the walls) by the pressure of the earth". (22)

The breast walls on the upper slopes or cuttings of a road rarely needed to be of great height. Parnell again cited Zelford’s specification for the Holyhead Road. They were to be:

... eighteen inches (45 cm) wide at the top; its foundation to be laid at least four inches (10 cm) below the bottom of the side drains, and is to be carried up so as to intersect the slope of the bank when falling at the rate of 2 horizontal to 1 perpendicular and the slope is to be formed in this manner for at least one yard (91 cm) from the back of the wall by means of a swarmed turf or stone pavement. The face is to have a curved batter at the rate of one inch and a half every foot from the top ... (23)  (See Fig 45/4).

The breast wall was thus a smaller version of the retaining wall, with a steeper batter and attention given to the stability of the slope above. The back of the breast wall could be made "... in the form of a rough dyke wall", but "every one of the back stones are (sic) to be regularly connected with the body of the wall, and not to depend upon the earth behind them". (24)

In Dobson's view the function of the breast wall was more to protect than sustain the earth. The strength of the wall was however, to be increased proportionately when the strata it supported inclined towards it (Fig. 60). Where the strata was inclined away from it, the wall needed to be little more than a thin facing to protect the ground from erosion. (25)
Gillespie described a similar non-supportive "slope-wall" composed of "rough stones from one to two feet thick laid without mortar with their faces at right angles to the slope" the purpose of which was to avert damage by water. (26)
SECTION IV/2/vii

BRITISH THEORY: RETAINING AND BREAST WALLS

Notes

1. Dobson, *Rudiments of the Art of Building*, p. 12; see also Gillespie, p. 182.
2. Ibid.
3. Law, p. 47.
5. Tomlinson, Vol. VI, p. 239.
11. Law, p. 49.
13. Ibid.
14. Cited in Parnell, p. 200. An error in the text has resulted in the specifications given for retaining walls actually being those for breast walls and vice versa.
15. Browne, p. 78.
16. Ibid.
18. Ibid., p. 19 ff.
19. Ibid., p. 20.
20. Browne, p. 79.
22. Dobson, *Rudiments of the Art of Building*, p. 22; see also Browne, p. 79.
23. Cited in Parnell, p. 200 (see note 14 above).
24. Ibid.
(viii) Bridges

The location of crossings over the obstacles of streams and rivers was, as has been discussed, most important in tracing a new line of road. Dobson commented that "river crossings' location is often the key to the rest of the work" and advised surveyors to "... pick the best or only spot and direct the road towards it". (1) With regard to the construction of bridges, Parnell observed that economic considerations were paramount and that the surveyor had, in some cases, to balance the cost of a large bridge with a shorter road against a small bridge with a more circuitous road. (2)

Since the bridges which were constructed in N.S.W. before 1833 were relatively simple in design, the detailed discussion of the large body of information about sophisticated eighteenth and nineteenth century bridge building is not relevant here. What has been extracted are the directives pertaining to the simple beam bridges built on the Great North Road. In 1820 Rees' *Encyclopaedia* included illustrations of such bridges (see Fig. 79) comprising stone abutments spanned by timber beams braced from below and with various types of handrailings. (3) Tomlinson gave a brief account of such a structure later in the century:

Another mode of (primitive) bridge building is to construct piers of stone at a short distance from each other to be spanned by single stones or slabs or by beams of timber. (4)

Regarding its construction, he observed that:

When this kind of bridge is used for shallow streams, and is composed of rough stones without mortar, the operation is simple, but in deep and rapid streams, the construction of piers of hewn stone indicates a considerable advance in the useful
arts, because a proper foundation is required for each pier. (5)

A more useful description of simple bridge building was included in Gillespie's book. He described the "simplest and most natural" form of a bridge as comprising:

... two timbers laid across a stream, or opening, which is to be passed over and covered with planks to form the roadway (cf. Figs. 123 and 124). (6)

Dobson described a similar simple log bridge as a temporary measure:

... for temporary bridges ... nothing can be better than a simple log bridge in 16 foot (4.8 m) spans built with logs not exceeding 12 inches (305 mm) in diameter. Such bridges are readily put up with a few simple tools; they do not involve the handling of heavy weights, and, if properly put together they will last for many years. (7)

The addition of stone abutments was an elaboration of this form. Gillespie wrote that the number and size of the timbers (or string pieces) was to increase with the stretch (width of the crossing) and he recommended that for a stretch of 16 feet (4.8 m), the timber should be about 15 inches by 8 inches broad (381 x 203 mm) and be placed at intervals of about 2 feet (609 mm). This most primitive bridge was, as Tomlinson pointed out, only suitable for short stretches. For those of greater width, supports from below the stretch could be placed at "proper" intervals. These could be of masonry, or upright props, or shores of timber, securely braced, and if the foundation was insecure, supported on piles (see Fig. 80a). They divided a long stretch into a number of shorter ones and supported the ends of the timbers by which each of them was spanned. Such construction is shown in Rees' Encyclopaedia as discussed above.

Gillespie described the methods of spanning the stretch where
a central support or pier was not feasible:

... if the opening be deep, or occupied by a rapid stream, it is very advisable to avoid the use of any such obstruction (supports). Means must therefore be devised for strengthening the beams so as to enable them to span large openings. This may be affected (sic) by supports from below ... the simplest are short timbers (bolsters or corbels) placed under the main ones to which they are firmly bolted and projecting about one third of the stretch. This will considerably increase the stiffness (see Fig. 80b). (8)

For spans up to 35 feet (10.6 m) a straining piece, as illustrated in Fig. 80d, could be interposed between braces, or struts, (Fig. 80c), since, otherwise, the latter would become "... so oblique as to lose much of their efficiency". Very wide stretches could be spanned by the combination of bolsters, braces and straining beams, as shown in Fig. 80e. (9)

An alternative in simple bridge building was crib-work. Dobson instructed that:

In crib work, the logs should be as nearly as possible of the same diameter, say from 10 to 14 inches (254 to 355 mm), and of lengths to be conveniently handled. The bottom of each log is left round, the top is notched to receive the log above it, and all the intersections are securely trenalled. (10)

He concluded that this was "an admirable substitute" for masonry, and could be used for building breast walls, crossing gullies or forming embankments in running water.
(ix) Conclusion

Although most writers neglected one or another aspect of road-engineering in their respective books, when taken together their work covers every conceivable facet of the subject in both principle and detail, as the foregoing survey indicates. Some variation in their recommendation occurred according to the writers' individual approaches, or to the contexts in which they wrote. Thus Parnell strongly advised the construction of elaborate and expensive structures in all situations, regardless of cost, while Dobson's Pioneer Engineering stressed economical planning and advised engineers to take the cheapest suitable alternative. Browne, describing roads for mountainous areas of high rainfall, included specification for massive masonry and drainage structures while in Tomlinson's account, such aspects are barely mentioned. The advice of road builders, though varying in these ways, was, however, rarely contradictory. The one great argument between them concerned the rival theories of Telford and Moadam regarding the construction of surfaces, and even in this dispute the advocates of one or the other view tended to conform unquestioningly to the directives laid down by one of the leading road builders.

The road engineers who arrived in N.S.W. in the 1820's armed with the general principles of the road building revolution, as here discussed, left material and written records about their attempts to apply these theories and recommendations to the new environment. In the following sections the translation of British theory into Australian practice, and the degree to which this was successful, will be explored.