How Did the Romans Achieve Straight Roads?

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Key words: Cadastre, History, Instruments, Surveyors.

SUMMARY

Accelerated Development – "Straight Roads speed communications"

How did the Romans build straight roads?

When driving on roads in Britain, if the road is straight for more than a kilometre it is common practice to say, "this must be a roman road"

One of the longest virtually ruler straight, visible, sections is the 53 km (33-mile) stretch of Ermine Street from Winteringham, on the Southern side of the River Humber, to Lincoln. (The present day B1207 and A15 follow its course).

This paper will look at how roman surveyors achieved such notable precision whilst restricted to the vision of the naked eye.

What do we know about how the Roman's set out and built their roads, what instruments were used and how were they used?
This paper will collect data on the processes which can be substantiated and describe instruments which are known, such as the "Groma" handed down from the Egyptians through the Greeks and used for laying out straight lines and right angles and the "Chorobates" used for levelling.

How could the Groma be used to build 53 km of ruler straight road? Reference to the stages involved in establishing a new road alignment today may uncover "more precision than art".

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1. INTRODUCTION

When driving on roads in Britain, if the road is straight for more than a kilometre it is common practice to say, "this must be a roman road"
I have always had an interest in why these roads were straight and how this was achieved. My interest in Roman infrastructure was encouraged when reading in Caesar's Gallic Wars how his legions built a bridge across the Rhine in 10 days – "It being below the dignity of a Roman General to cross by boat".
I have collected together information available in the public domain to try and explain how the Romans achieved such Surveying success without the use of optical instruments.
I discovered during my research that whilst there is literature on building aqueducts and towns there is no literature on how the Romans achieved straight roads. Our conclusions must therefore be based on circumstantial evidence.
I set out the information collected to allow development of a conclusion. Information has been mainly based on the English experience.

2. TIMELINE

2.1 The Roman Period

Roman republic 510 BC to 44BC; Roman Empire 44 BC to 476 AD

2.2 The period of Roman Occupation of England & Wales

AD 43 Claudius Invasion;
AD 410 Honorius tells the civitates of Britain to arange for their own safety

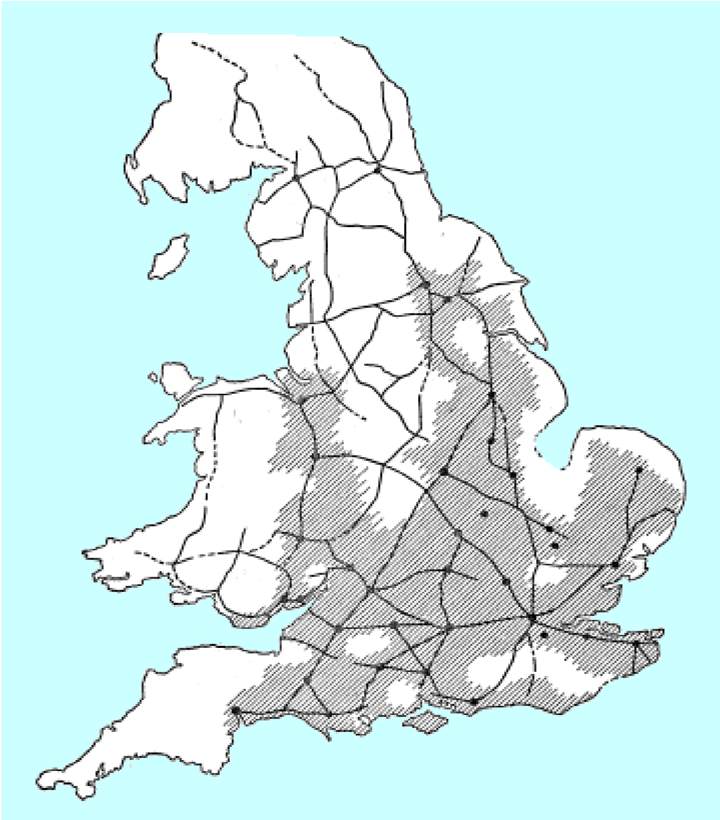
2.3 The Main Road building Period

There are some 10,000 km of established Roman roads in England & Wales. The majority of these were planned and built during the first century AD between AD60 and AD 90. This compares with 9000 km of Strategic Motorway and Trunk Roads in England & Wales today.

2.4 The Introduction of Straight Roads

Straight alignment of major roads seems to date from a law enacted by Tribune Gracchus in 123 BC. Early roman roads straightened and improved existing tracks. Vespasian advancing into Galilee in AD 67 records that he straightened and leveled existing tracks. The Roman Army needed good roads to allow its support and supply train to function. Many of the Strategic Highways built by the Romans followed the Tactical roads established as the Army advanced. The Army's advance and consequently the tactical roads most easily followed and improved existing tracks which existed in Pre-Roman Britain.

2.5 The extent of Roman Roads in Britain.



The Army built the Initial Strategic Roman road network to facilitate military communications, particularly between the legionary fortresses of Exeter, Lincoln, Gloucester, York, Caerleon, Wroxeter and Chester. Strategic roads often followed the Tactical Roads.

The Initial Strategic Network

Period	**From**	**To**	**British Name**	**Distance (Km)**
Julio-Claudian	London	Richborough	Watling St	110
AD 43-49	London	Chichester	Stone St	90
	London	Lincoln	Ermine St	200
	London	Wroxeter	Watling St	220
	London	Colchester		90
AD 50-68	London	Gloucester		175
	London	Exeter		200
	Exeter	Lincoln	Fosse Way	354
Flavian	Lincoln	York	Ermine St	120
AD 69 to AD 96	Wroxeter	Chester		65
	Gloucester	Caerleon		70
	York	Corbridge	Dere St	150
	Chester	Carlisle		200
	Caerleon	Caernarfon		130
				2174

2.6 The Modern Network

Modern England & Wales				
Type	**England**	**Wales**	**Total (2006)**	**Accumulative**
Motorways	3,007	141	3,148	3,148
Dual Carriageway Trunk	2,634	348	2,982	6,130
Single Carriageway Trunk	1,715	1,199	2,914	**9,044**
Dual Carriageway Principal	3,935	205	4,140	13,184

3. CONSTRUCTION PROGRESS

3.1 Tactical (Assault) Roads

When Plautius's invaded England in AD43 his Task force is likely to have consisted of 20,000 legionnaires, 10,000 cavalry, 15,000 axillaries, 6,000 support personnel and 15,000 animals. A Tactical road would be required to support and provide a supply line for carts and mules.
The Royal Engineers studied the time taken to build the Richborough – London tactical road, which would have followed close behind the advance of the Roman troops.
Allowing 1000 men working to clear trees and shrub, level a central carriageway marked with timber kerbs, provide minimal drainage and provide a track way over swamps they have estimated the 119 km from Richborough to the Thames at Westminster would have taken only 69 days to construct. Times were varied to allow for four ground types – Grassland, Forest, Heathland and Swamp. This tactical road would be used for bringing up supplies, for the movement of troops and reinforcements and for medical evacuation.

This tactical road would have only been suitable for use during the summer (hostilities) season because the central carriageway was not substantially built or metalled.

4. ROMAN ROAD DESIGN

4.1 Purpose

Roads provided the communication arteries and were designed to allow rapid movement of troops and military supplies, trade, communications and the official post at all times. The surface had to support horse or ox drawn carts which had hard wheels and limited suspension.

4.2 Design

4.2.1 Requirements

Ruts in roads caused by wagons wheels have been measured at 4ft 8.5 inches wide. To allow two wagons to pass needed a minimum of 10ft or 3.3 m. Surfaces needed to be able to support hard wheels with double axle carts and single axle chariots in all seasons. Roads had to be capable of allowing imperial messages to be transported at 20 m.p.h [200 miles in a 10 hour day]. Straight lines provide the shortest distance between points.

4.2.2 Observed Design

Roads occupied a wide strip of land varying from 25m (Ermine St) to 100m wide (Ackerman St) with a central paved highway, deep ditches each side, wide cleared partly metalled verges for pedestrians and animals and outer ditches.

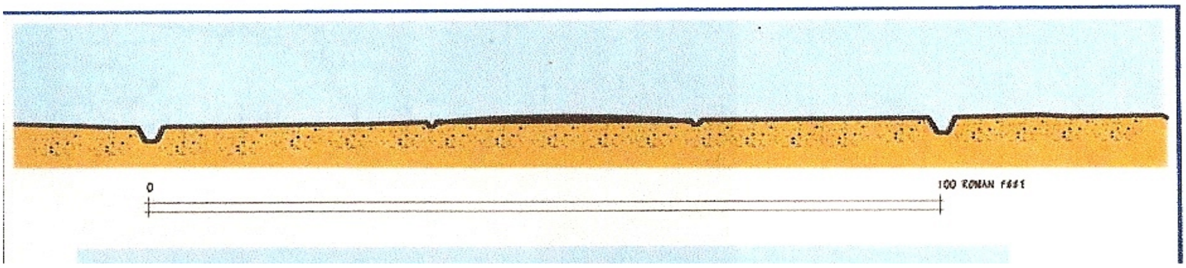


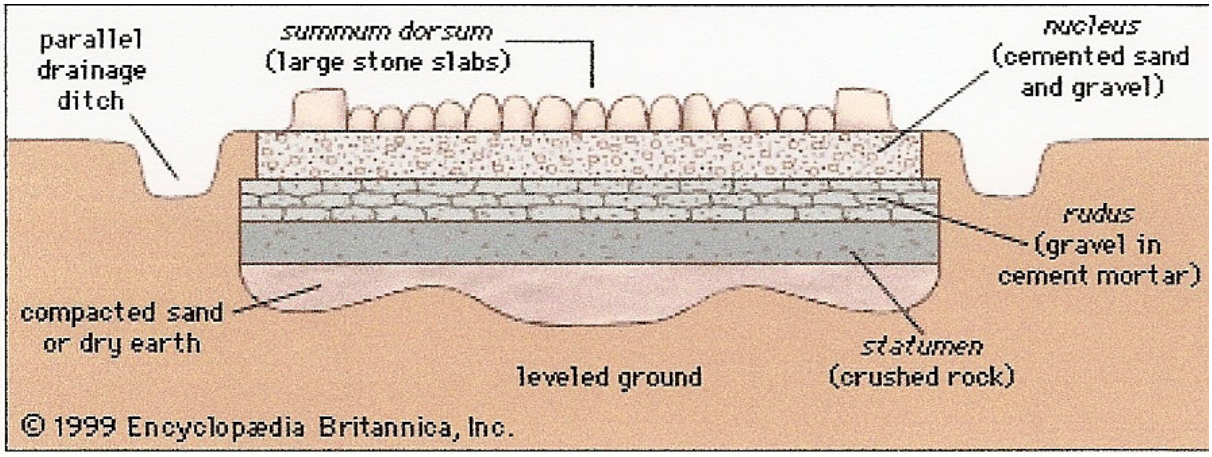
Fig I

Roads were aligned as a series of straights with changes of direction taking place at high points.
Roads were aligned along ridges and watersheds wherever possible.
Rivers were preferably crossed at fords, which were then mainly paved.
Straight lines were followed up to 1 in 6 slopes at which time they started to zigzag.
Where deviations for natural features (such as valleys/fords) had to occur the straight route was picked up again on the other side of the feature.
The longest straight stretch of road in England is the 33-mile (53 km) stretch of Ermine Street from Winteringham, on the Southern side of the River Humber, to Lincoln.
The Fosse Way from Lincoln to Axminster a distance of 200 miles (300 km) deviates by less than 6m (10km) from a straight line between the two forts despite deviations to follow watersheds. Inspection of series of straights on Google Earth indicates no deviation (within hedge lines for 18km lengths.

4.2.3 Construction

Vitruvius about 30 BC described the process of construction of the highway [probably in Rome] as follows:-
The field engineer, assisted by a stake man aligned the road with a Groma and ran levels with chorobates.
A plow was used to loosen the soil and mark the trench (“fossa”) margins. Workers dug out trenches down to firm material.
[If no firm material was found timber piles or floating timber mattresses were installed].
[Cross-drains or culverts were installed]
The bed was tamped firm. The foundation of lime mortar or sand was laid to form a level base (“pavimentum”)

A foundation layer generally 4 to 5 ins of handleable stone cemented together with mortar or clay the ("statument") was constructed from 10 ins to 2 feet deep,
The next course ("rudus") was 9-12 ins of concrete filled with shards of pottery or stone.
Followed by the ("nucleus") a concrete made from gravel or sand and lime poured in layers with each layer compacted with a roller. This layer was 1 foot at the sides and 18 ins at the crown providing a drainage camber to the highway.
The top course ("summum dorsum") was polygonal blocks of stone 6ins thick.



In the country the Romans appear to have maintained: -
The pavement layers of 1-1.5 m as :-

A bottom layer of stone
A middle layer of softer material such as sand or gravel
A metalled surface of gravel, paving stones, crushed iron slag or similar

Most roads were edged with kerbs, which in towns became a high stone walkway.

The highway was built on an ("agger") embankment of material dug from the ditches. It was 45 to 50 ft wide and 4 to 5 ft high depending on the importance of the road.
Public Roads ("Vitre publicae") could be 40ft (5-12m) wide whilst secondary roads (Viae militares were less. Local roads ("actus") might only have a 9 to 12 ft (3-6m) wide Agger.
Roads were constructed in the summer season probably April to September.
Roads were initially constructed by the military but subsequently by labour conscripted locally.
Reports identify that the Romans would have had no issues over land ownership or use when installing military roads i.e. they could construct on straight lines with no consideration of ownership.

It is clear that the Romans used different layers of materials but that all roads were designed and engineered to last. They had good alignment, substantial drainage and a maintainable top surface.

5. SURVEYING

5.1 Surveyors

5.1.1 Trade Association

Roman colonies controlled the land outside the urban centers (“territorium”) very carefully. Land was divided to regular patterns for ownership and taxation purposes by land surveyors (“agrimensores”). These land surveyors, known collectively as “Corpus Agrimensorum Romanoram” or “Corpus” had their own manuals, training and methods of work.

5.1.2 Disciplines

Agrimensors were skilled at using the Groma together with sighting rods (“decempeda”). Specialist skilled Groma users were “Gromatici. Agrimensors were principally field measurers.

5.2 Instruments

5.2.1 Groma

The Groma consisted of a vertical iron staff (“ferramentum”) about 5ft long pointed at the lower end and with a cross arm 10 inches long pivoted at the top which supported the main aligning elements – the revolving “stelleta” with arms about 3.5 ft across.

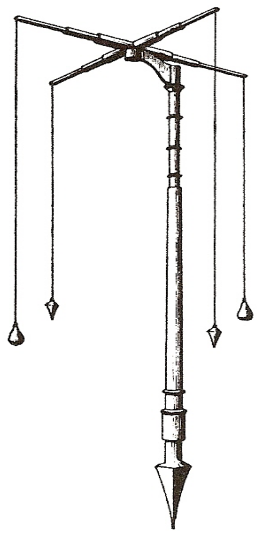


Fig iii

A central plumb-bob may have hung from the centre over the control point.
Stringlines could be protected from wind using tubes or immersing the tips of the plumb-bobs in water.

The metal parts of Groma have been found in Pompeii

5.2.2 Chorobates

The chorobates is described as a rod 20ft long with duplicate legs attached perpendicularly at each end. Diagonals connect the rods and legs. Both diagonal members have vertical lines scriven in them over which plumb bobs hang.
When the instrument is in position and the plumb lines strike both the scribe lines the instrument is level. If the wind interferes the water level at the top of the horizontal is used. Vitruvius instructs the groove should be 5 ft long 1 digit wide and 1.5 digits deep.

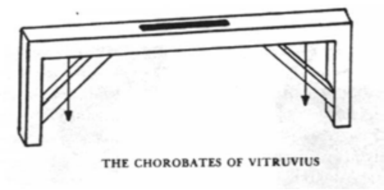
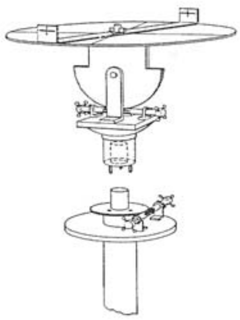


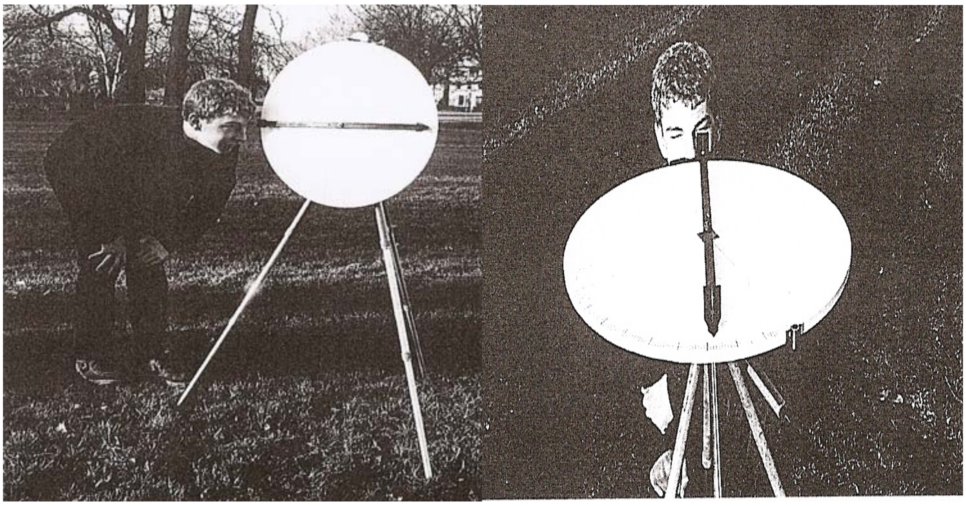
Fig iv

5.2.3 Odometer

Certain wagons had special circumpherence wheels and cogs, which dropped a small stone ("calculus") in a box every roman mile.

5.2.4 Dioptra





Hero of Alexandria has best described the Dioptra. It was used for both horizontal and vertical measurement. A properly built Dioptra would have involved significant engineering and close control when used. Calibration and skill were required in its use.

5.2.5 Decempeda

The decempeda was a calibrated measuring rod made of hard wood with metal ends. It was probably 10ft long and could be joined with another to allow end over end measurement.

5.2.6 Other Instruments

Ropes were used for measuring distance. They were stretched between stakes and hung with weights to eliminate further stretch. Tests carried out with Jute ropes 120 ft long with knots/beads and braids as markers at 1 ft intervals have shown variations in measurement of about 2%.

5.2.7 A Surveyors Workshop

The surveyor Veru had a workshop in Pompeii which was uncovered and still held a portable sundial, a measuring rod, a folding ruler and bronze compasses

5.3 Application

5.3.1 Terms Used

Land was laid out using a 120 ft ("actus") grid equivalent to about 35.5m.
1 foot (pedes monetales") = 0.295m
Land information systems started with surveying ("limitatio") and the establishment of survey markers ("termination") followed by boundaries ("limites") [initially ditches and field boundaries]. Where the divisions were squares normally 20 actus x 20 actus the survey was known as ("centuration"). The whole information system was ("Cadastre")

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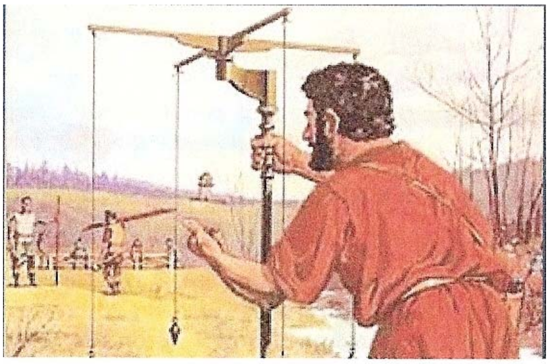
5.3.2 Application of the Goma

Roads in camps were established by setting up over a point and using the Groma to establish a right angle.
Areas of fields were measured by setting out two right angle lines joining the ends and measuring the offsets at right angles.

Corinth for example [which was rebuilt as a Caesarian city] was laid out to a 32 x 15 actus grid. The land surrounding used a series of actus grids linked by whole number ratio triangles [1/1, ½, 1/3, ¼, 1/5, 1/6, 1/7, 1/8, 1/9, 1/10]
Straight lines can be extended by viewing through a Groma and establishing a line of pegs. The Groma can then be moved forward, it is then positioned until it exactly lines up with the pegs and then sighting the other way the line is extended.

The Romans understood and used algebra and trigonometry based on Euclidian geometry. They were therefore able to re- calibrate the Groma using 3/4/5 triangles



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5.3.3 Application of the Chorobates

Using two or more chorobates set up horizontal, the vertical distance could be established by sighting along the uphill instrument. The decempeda [or ten foot surveyors rod] could be used as the staff.

5.3.4 Use of the Dioptra

Use of the Dioptra was more complicated than the Groma. It could be used for vertical or horizontal measurement. Combined with a staff which had a sliding target the instrument could be used as a level.
Used flat it had the properties of a plan table.

5.3.5 Application of other instruments

The range of Roman instruments was restricted to the vision of the naked eye.

There is no report of the use of the compass although they were found in Pompeii.
Large scale maps were produced although these were distorted in the E-W direction because of the problem of locating relative latitude and longitude
Measuring ropes were used to measure distance combined if necessary with plmbbobs and tensioning devices.

6. SETTING OUT ROADS

6.1 Problems

A Groma could potentially be used to establish an extended straight line, however assuming an error of 0.5mm in 3ft could give 15m in 10 km.
How does the surveyor know which way to go?
Did the roads lead between established towns or forts or were the towns established after the roads had been set out?

6.2 Information available

Roads were initially set up to connect Forts. The forts would have been positioned to meet strategic military needs.
These needs would have to be based on an understanding of the geography both physical and political for the region.
The main strategic highways were therefore established after the Legionary forts had been set up.
Highways align with specific points at the forts [primary setting out points] such as the main gateway to Colchester.

Later towns and economic areas were set out from the main highways using these highways as the base line with the "decumanus maximus" or principal axis referenced to it.

6.3 Establishing a road alignment today

If we consider roads that were constructed in the 19^{th} Century the approximate sequence would be: -

Broad Survey of the terrain and establishment of possible routes.
Choice of routes along watersheds to reduce the need for bridges and the results of run-off
Decision on the preferred alignment
More detailed survey of that alignment and establishment of primary setting out points
Establishment of secondary setting out points along the route for use by the road builder.
Sourcing of material for the road.
Establish centerline/clear trace
Set out boundaries clear between boundaries
Construct road bed including drainage.

6.4 Most likely scenario for building short Roman roads

Reconnaissance of the route
Plotting on crude maps
Establish approximate directions from the sun and stars
Establish main survey stations at inter-visible points say 2/3 km apart along the line.
Stake out the route between the primary setting out points using Groma or Dioptra by lining up and ranging in or centering and ranging forward or back with use of Ranging poles
Look at gradient and crossings and allow deviations for local problems from the established straight line.

6.5 Most likely scenario for building longer roads

Reconnaissance of the route
Plotting on crude maps
Establish approximate directions from the sun and stars
Establish main survey stations at conspicuous high points along the route. These high points to be used as change points for a series of straights.
Establish lines between change points using ranging poles flags or painted targets
Major sighting points could be established at night using fires.
[Beacons warning Constantinople were an average of 90km apart with 9 beacons covering 725km].
In UK trials have shown that a fixed fire 5m high can be seen up to 30km away.
Braziers on poles could be used for signaling for distances of up to 6/7 km

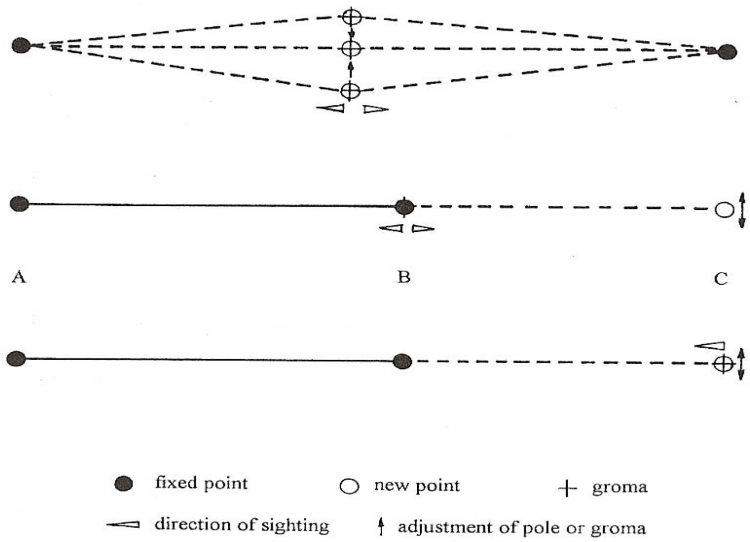
6.6 Most likely scenario for building long straight roads

Reconnaissance of the route
Plotting on crude maps
Establish accurate relationship between start and finish using celestial observations with armillary astrolabe and gnomen as described in Ptolemy's geography
Establish main survey stations at conspicuous high points along the route. These high points to be used as setting out points to establish the straight line of the road and to establish change points.
Establish lines between change points using ranging poles, flags or painted targets
Major survey stations to be identified at night using fires, angles ranged in using Dioptra

6.7 Establishing the straight sections

6.7.1 Short inter-visible straights

Up to 2/3km - Range In by eye. Move ranging rods by hand or with flags
Up to 4/6 km – Range in from a central point arranged by moving the Groma until both points line up.



Up to 6/7 km – range in portable braziers using hand held braziers to indicates movement or use smoke if daylight conditions permit.

<u>Short visible or non-visible straights</u>

Up to 4/6 km – Range in 2/3 km each way from a central point arranged by moving the Groma until both points line up.

Up to 12/14km – Range in at night moving the Groma until it lines up with two braziers at the start and finish points

<u>Long-non visible straights</u>

Establish two high points along the approximate alignment.

Measure the distance between them

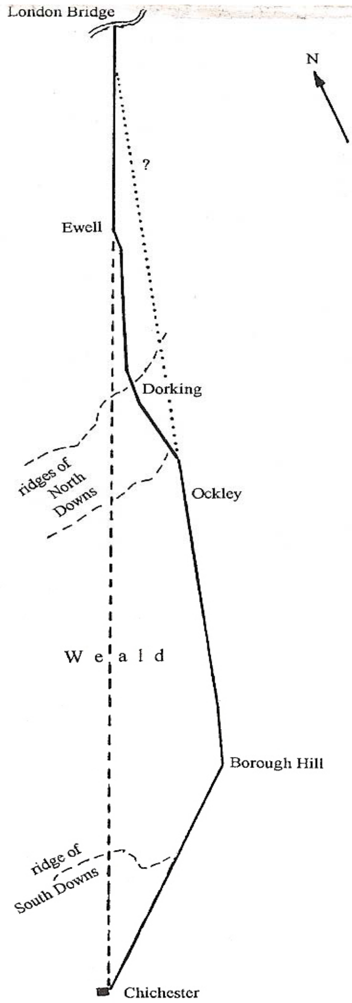


FIG. 11.10. Stane Street.

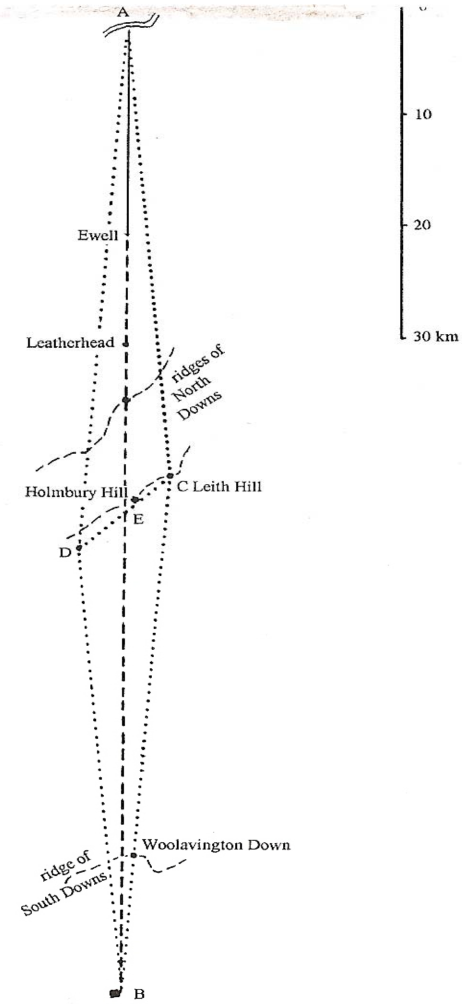


FIG. 11.11. Stane Street aligned by geometrical construction.

There is a frontier line established in AD155 in Germany through a heavily wooded area which only deviates by +- 1.9m in 29 km from a dead straight line.

7. CONCLUSIONS

Roman roads were established throughout the Roman Empire. They were equipped with rest houses every 15 miles [the average days travel]. Strip maps [such as the Antonine itinerary] were available to travelers to describe the route on all the major roads. Roads were a major investment by the empire.

Roads can be seen to be a colossal undertaking and a significant investment in infrastructure.

From the time of Grassus, when building roads straight became a legal requirement, for some 500 years the art of surveying was used to establish straight roads without the use of optical instruments.

The Romans benefited from speedy communications through well-designed and engineered highways. This was not repeated in Britain until the trunk roads of the 19th century.

A key component of these roads was the setting out.
Agrimensors who had their own professional organization were standard surveyors.
Professional Surveyors trained in the use of the instruments available could clearly achieve high degrees of accuracy with their instruments and had both the geometric skills and the technology to direct construction of long straight alignements.

Military Surveyors traveling with the Army had a special status as “Immunes”. Immunes were experts in their various fields and exempt from the more tedious or dangerous soldiers tasks. Immunes included medical staff, engineers, surveyors and priests. Their intelligence allowed them to rise quickly in the ranks and they were ranked as Praetorian Guard in the higherarchy of the Army.
Military Surveyors were responsible for locating campsites and forts and establishing the alignments of roads.
It is nice to think of them as the high priests of the surveying profession.

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BIOGRAPHICAL NOTES

Richard Hucker MBE BSc.(Hons) FICE, F.Inst.CES, F.ZwE., ICIOB is a Chartered Civil Engineer who has been involved in the Development & Construction of Civil Engineering Projects, particularly Highways for over 40 years, . Richard graduated from City University and worked on a variety of different road types in the UK before becoming an Agent for a major UK contractor. Richard then moved to the Middle East on a heavy civil project progressing through UK, Europe, Oman, Zimbabwe, Botswana and Malaysia as Country Manager before setting up a Project Management company in Egypt. Richard has been involved in the development of skills through his involvement in local institutions, setting standards for membership and sitting on panels reviewing national standards. Richard presented a paper in 2007 at the Hong Kong working week on Planning & Development in Northern Iraq having been awarded an MBE in 2006 for his services to British business in Iraq. Richard also gave papers in 2008 in Stockholm on Recruitment & Retention of Surveyors. Richard is a member of the Management Panel for the Institution of Civil Engineers is a Fellow of the Institution of Civil Engineering Surveyors and

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