Road building

The first roads used by man were probably beaten out by the hoofs of animals as they made their way between feeding and watering places. Routes that began as mere cattle tracks or hunting and supply trails developed after the invention of the wheel into harder-wearing roads criss-crossing the ancient world and linking great trade markets. The Romans constructed an extensive road network [Key] to meet the military and political requirements of the empire and many of their routes are still important.

Stone paving

Few authenticated records exist of pre-Roman road paving. But given the known skill of the ancient stonemason, we may assume that heavily used roads of the earliest civilizations were surfaced with slabs of cut stone. A drained earthen track becomes compacted by foot and hoof but cannot stand up to the wheel, which gradually cuts and breaks the surface.

The engineering of Roman roads [3] is well documented. Descriptions are detailed and some roads lasted so well that the original formation has been discovered, almost intact in places, by archaeologists. The Appian Way, started in 312 BC, which linked Rome with Brindisi, was typical. About 4.5m wide across its two-way central lane, it was built in five layers and had three features to ensure drainage; it was constructed above ground level with a cambered surface and flanking ditches. The wearing surface was of crushed lava (plentiful in southern Italy) on a gravel core. The larger stones of the base course of many Roman roads were mixed with lime mortar as a binder or with pazzuloana (natural volcanic cement), forming what was virtually a concrete footing. The surface of Roman roads varied with local materials.

Construction was undertaken using skilled labour from the army, together with unskilled local assistance (or possibly slaves), under the supervision of an engineer. These skills were lost with the fall of the empire and standards of European road building and maintenance rapidly declined.

Modern road technology evolved in eighteenth century France. The *Corps des Ingénieurs des Ponts et Chaussées* was set up in 1720 within the French army. Twenty-seven years later the *École des Ponts et Chaussées* was established as a state college at which civilians could study. It was Pierre Tresaguet (1716-96) who designed and built the first roads that combined good engineering practice with sound economics. He taught that there were two essentials for a lasting road – a firm foundation protected by a water-resistant surface [6].

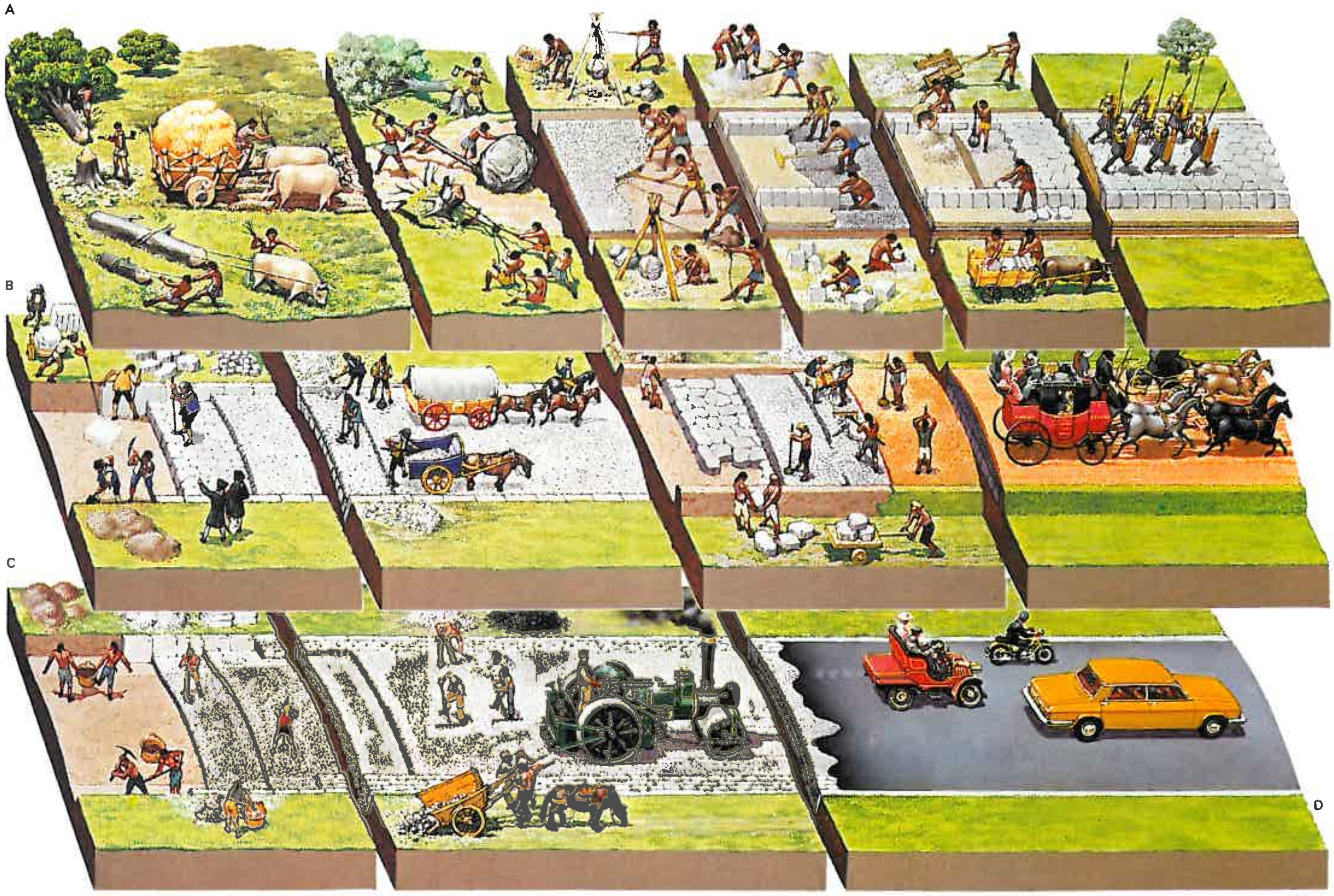
Influence of McAdam

The French lead was soon followed elsewhere in Europe and the names of two British engineers became closely associated with improved road design. Thomas Telford (1757-1834), originally a stonemason, built roads similar in section to those of Tresaguet. But Telford's pavement was costly and it was a Scotsman, John McAdam (1756-1836), who found a way to cut costs without impairing efficiency. McAdam eliminated the deep foundation, recognizing that it is the soil that ultimately supports the weight of traffic, and that compacted soil, kept dry, will support any load. McAdam's road [4] was cambered

CONNECTIONS

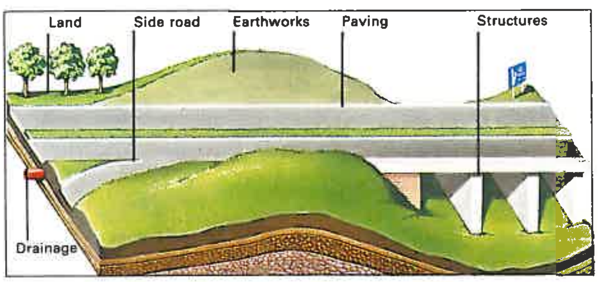
See also
Small technology and transport
Traffic engineering

In other volumes
Earth moving machines (6)
History of transport (9)
Carts, coaches and carriages (9)
History of automobiles (9)



1 Road construction methods grew from simple compaction of early routes by foot and horse-drawn traffic. The Romans [A] made their routes more permanent by removing obstacles, laying foundations of gravel, surfacing with crushed stones or paving slabs and leaving drainage ditches at both sides. In the eighteenth century [B], major roads were built of tamped gravel on top of a foundation of large blocks. Roads in the nineteenth century [C] were similar but were sometimes raised and had an upper surface of rolled gravel. With the vast increase of traffic in the twentieth century and the introduction of heavy vehicles [D], roads had to be made more durable. Most modern roads have a lean concrete base with a surface composed either of reinforced concrete or of rolled asphalt.

2



2 A cost breakdown for a modern motorway shows that earthworks are the most expensive item.

Earthworks	25%
Paving	18%
Structures	18%
Drainage	7%
Land	4%
Side roads	4%
Engineers' fees and miscellaneous	24%

for drainage and was surfaced with stone chips which were crushed and rolled by the steel-clad wheels of his time into a smooth water-resistant surface.

The McAdam pavement served its purpose well until the invention of the rubber tyre. The tyre no longer compacted the crushed stone surface, but seemed to suck the finer material from between the larger stones until the surface broke up. A binder was needed and found in natural tar. The new surface was called tarmac.

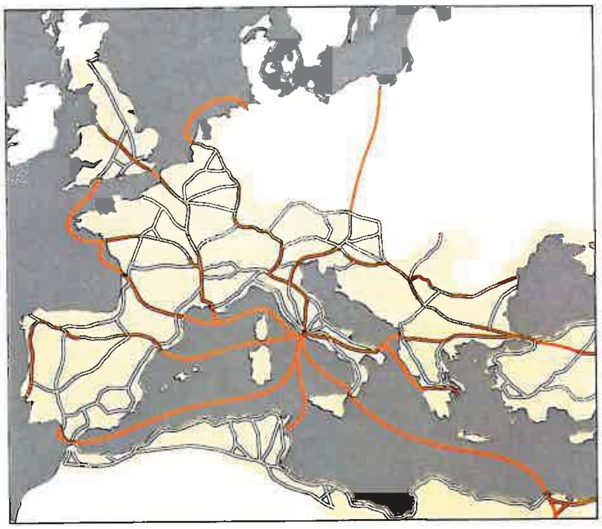
Concrete paving

The modern "flexible" or "black-top" pavement has a wearing surface layer 3-5cm thick laid on a bitumen (or tar) and aggregate layer up to 10cm thick over a 25cm base layer, laid on a sub-base course of any locally available granular materials such as stone or clinker. In a typical reinforced concrete "rigid" pavement a compacted granular base course is covered with a concrete slab up to 30cm thick with a mat of steel reinforcement 5cm below the surface. This design spreads the heavy-vehicle axle-loads over a wider area. The wearing surface may be formed from concrete or bitumen and fine aggregrate. Increasing traffic densities and the use of heavier vehicles places considerable stress on the road structure and heavier construction is used for major routes.

The rapidly expanding need for more and more roads has led to the development of sophisticated road-making machinery. Giant scrapers, graders and other heavy earth-moving machines are used to prepare the roadbed and lay the footing. Machines for automatic laying of an asphalt surface to a predetermined thickness are commonplace; advanced models can lay and consolidate a 20cm asphalt layer in one pass, providing a finished black-top pavement.

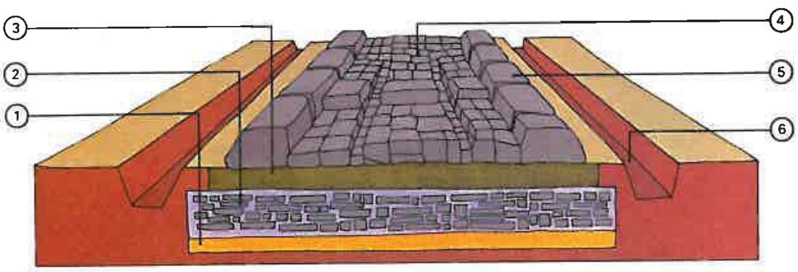
The modern automatic concrete paver [7] spreads and tamps a continuous slab of concrete up to 30cm thick and 5m wide, handling about 300 tonnes of material an hour, its hopper fed by tipper trucks. Reinforcement, in the form of mats of welded steel rods, is either sandwiched between two layers of wet concrete or pushed down into the body of a single slab.

KEY



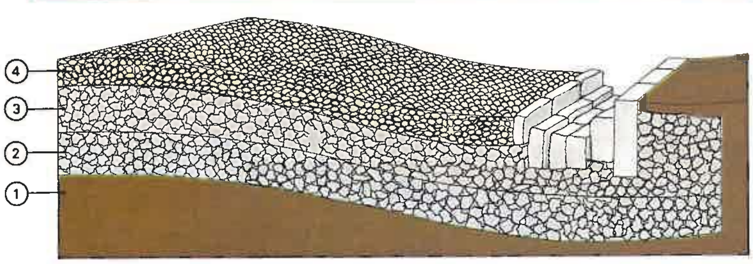
The Romans built 85,000km of roads linking Rome to its overseas centres of supply. These roads are distinguished for their straightness and durability. Major land and water routes are marked on this map in orange; the other routes are secondary.

3



3 The Roman road pavement was based on a compacted earth footing [1] with a layer of small stones in mortar [2] and above this hard filling [3] and a slab surface [4]. At the sides were retaining stones [5] and ditches for drainage [6].

4

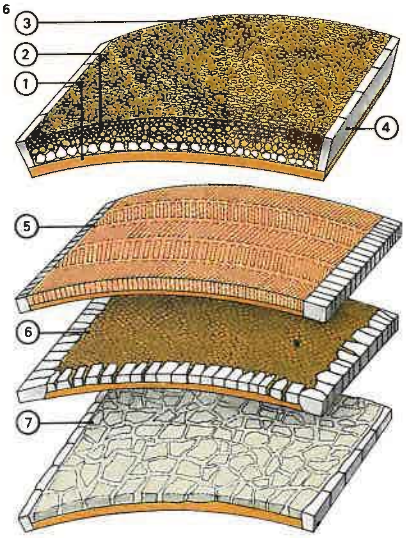


4 McAdam's pavement consisted of a compacted, cambered earth footing [1], a 10cm base course of stones [2], a 10cm middle course of stones [3] and a final wearing surface of small stones [4]. Steel wheels crushed and rolled the stones into a smooth surface.

5

5 A typical modern pavement has a granular sub-base [1], a 25cm base layer of lean concrete [2], a 6.5cm layer of tar or rolled asphalt [3], a 3.5cm wearing course of rolled asphalt [4], a concrete haunch [5] and a hard shoulder of asphalt on a concrete base [6].

6



6 Tresaguet's road was constructed in the latter half of the 18th century. It consisted of a foundation of heavy stones, which was rammed into an earth base slightly below ground level [1]. This was then covered by a 16cm layer of medium-sized stones [2], followed by an 8cm hard wearing surface of walnut-sized, tamped stones [3]. Retaining stones [4] were then placed at the sides. The construction ensured good drainage. Other surfaces included herringbone [5], *opus testaceum* (brick and tile) [6] and cobbles [7].

7

7 Road making is automated in the modern concrete "train". Ready-mixed concrete is fed into a paver which extrudes an even layer as it creeps along. This layer is compacted with poker vibrators. After a mat of steel reinforcing has been laid over the wet concrete a second paver places another layer of concrete over the steel. A vibrating beam is used to compact this thin layer without disturbing the steel. Surface irregularities are then eliminated with an automatic screeding machine carrying two transverse vibrating metal strips which spread a slight wave of excess mix over the surface. After final levelling by means of straight edges manipulated by hand from a travelling bridge, mechanical brushing is used to produce a non-skid surface. The concrete is protected with waterproof tenting.

Traffic engineering

Modern road systems evolved over many hundreds of years out of the network of routes that linked villages and townships across the length and breadth of every country. In early times, the farmer's cart threaded its way between fields, skirting woods, avoiding water and seeking the most convenient routes across hilly ground. In mountainous country, the principle of siting roads in the general direction of contours was developed to maintain reasonable gradients.

Development of road construction

By 1826, the British engineer Thomas Telford (1757-1834) had reconstructed the road from Shrewsbury to Holyhead to specifications which minimized curvature and gradient and provided perfect drainage. Now a part of Britain's A5 highway, his road was a model of its time, providing what is still a top-gear highway for the whole of its length.

Special highways for fast motor traffic appeared in North America and Europe in the 1920s, notably around Milan where a system of single-carriageway autostradas was developed by private enterprise. In Germany, Adolf Hitler was impressed by the military potential of these roads and a vigorous programme of highway building began with the Frankfurt-Darmstadt autobahn in 1933-5. With subsequent design improvements, the modern high-speed freeway or motorway emerged. High speeds do not necessarily imply danger because a segregated freeway can handle high-volume, high-speed traffic flows with far greater safety than an arterial road with cross-junctions, kerbside parking and other hazards. Typically the accident rate for a freeway is less than one-third of that for non-urban highways and about one-tenth of that for roads in built-up areas. Most countries impose maximum speed limits, of around 110-120km/h, for safety reasons while minimum speed limits (50-60km/h) are sometimes set to maintain the traffic flow.

The basic features of freeway design [1] are simple: segregation of the freeway traffic with no building along the carriageway, which is usually fenced off; separation of up and down traffic by central reservations and barriers; no cross traffic or junctions – vehicles join and leave on slip roads that gradually merge with the main carriageway; wide marked lanes of a standard width; and easy curves and gradients. Old roads can seldom be upgraded to these standards so most motorways are normally built as new roads, although such developments often create considerable public opposition.

Urban freeways are designed for lower speeds with more frequent access for local traffic [4]. Because it is often impractical to drive urban freeways through existing cities at ground level, they are often built as elevated structures or in tunnels. Although tunnelled roads are more costly, they may justify their expense by avoiding the damage elevated roads do to the environment.

Traffic controls

Some of the earliest attempts to control traffic were made in ancient Rome. During the first century AD, cart traffic was banned from the city during daylight hours. With the expansion of trade and commerce during the Renaissance, several European cities introduced rudimentary traffic regulations,

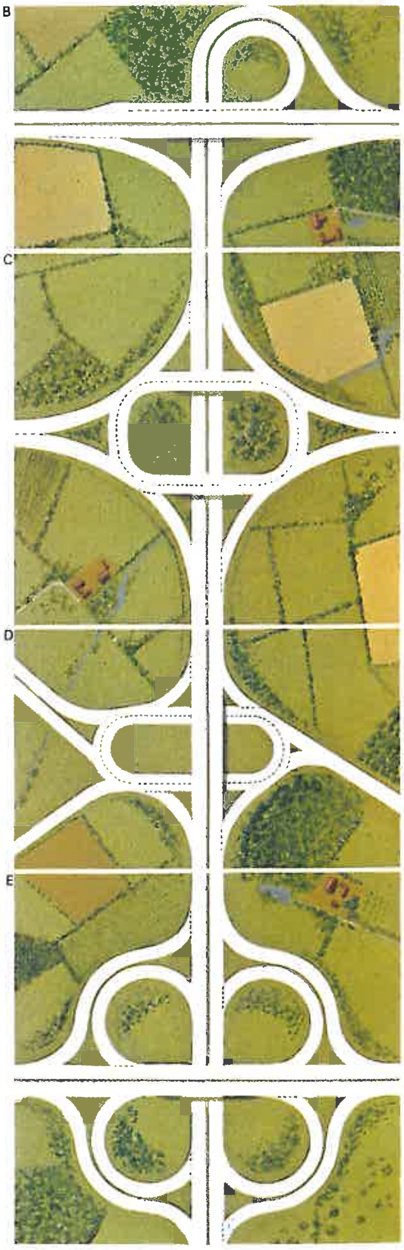
CONNECTIONS

See also
Small technology and transport
Road building
Cars and society
Trams and buses
Modern urban transport

In other volumes
History of transport (9)
Carts, coaches and carriages (9)
History of automobiles (9)

1 A

B C D E



1 Freeway interchanges are designed to minimize traffic conflict. Different needs are met by a number of designs. [A] The Almondsbury interchange between Britain's M4 and M5 motorways allows traffic to flow safely towards any destination without much loss of speed. [B] The trumpet interchange provides a freeway T-junction with three-way access and minimum conflict. [C] Where a freeway is crossed by a major road, the major road is divided to form a roundabout either over or under the freeway itself. [D] Purpose-built junctions are designed to connect a country road network with a freeway. [E] The classic "cloverleaf" freeway interchange achieves safe access to and from all directions with little traffic conflict. Traffic that is changing direction must reduce speed in compact interchanges of this form.

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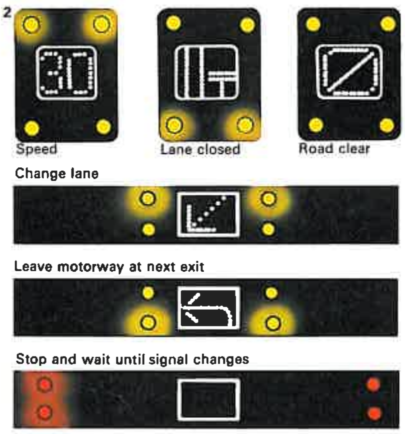

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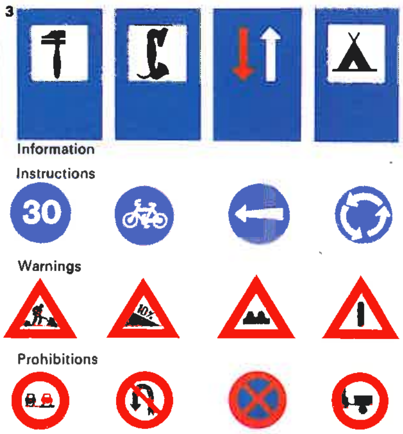


2 Electronic signs on British motorways are operated by police at central control stations. They are normally blank but can be activated to show a variety of illuminated symbols. Surrounding these signs, coloured lamps flash to draw motorists' attention.

3 Language problems have been overcome in recent years by the introduction of a standardized system of road signs which can be recognized by motorists internationally.

including one-way streets and parking restrictions. Leonardo da Vinci (1452-1519) envisaged separation of traffic on two levels.

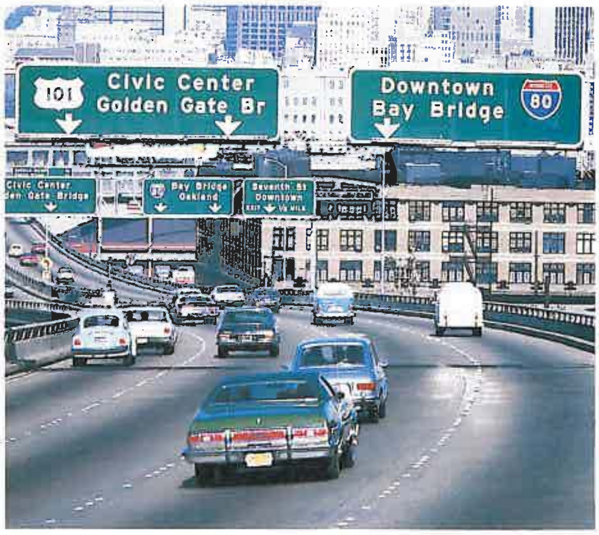
The arrival of the motor age at the turn of this century saw the tentative beginning of scientific traffic engineering with the adoption of a traffic code for New York in 1903. Customary rules, such as keeping to the left in Britain and giving way to the right in other European countries, began to be enforced by law. The introduction of safety road signs [2], automatic traffic lights at urban junctions and roundabout systems followed. Traffic engineering is a twentieth century science, born out of the hazards brought to human societies by a torrent of motor vehicles. Its object is to provide safe, convenient and economic movement of vehicles and pedestrians.

More recently, traffic engineering has been defined as the science of fitting roads to traffic by planning and design, and traffic to roads by regulation and control, in order to achieve maximum capacity with safety. This depends on analysis of traffic flows, congestion and accidents. On motorways, increased capacity at high speeds with safety is sought. The road designer must achieve these aims with the least harm to the environment.

City traffic

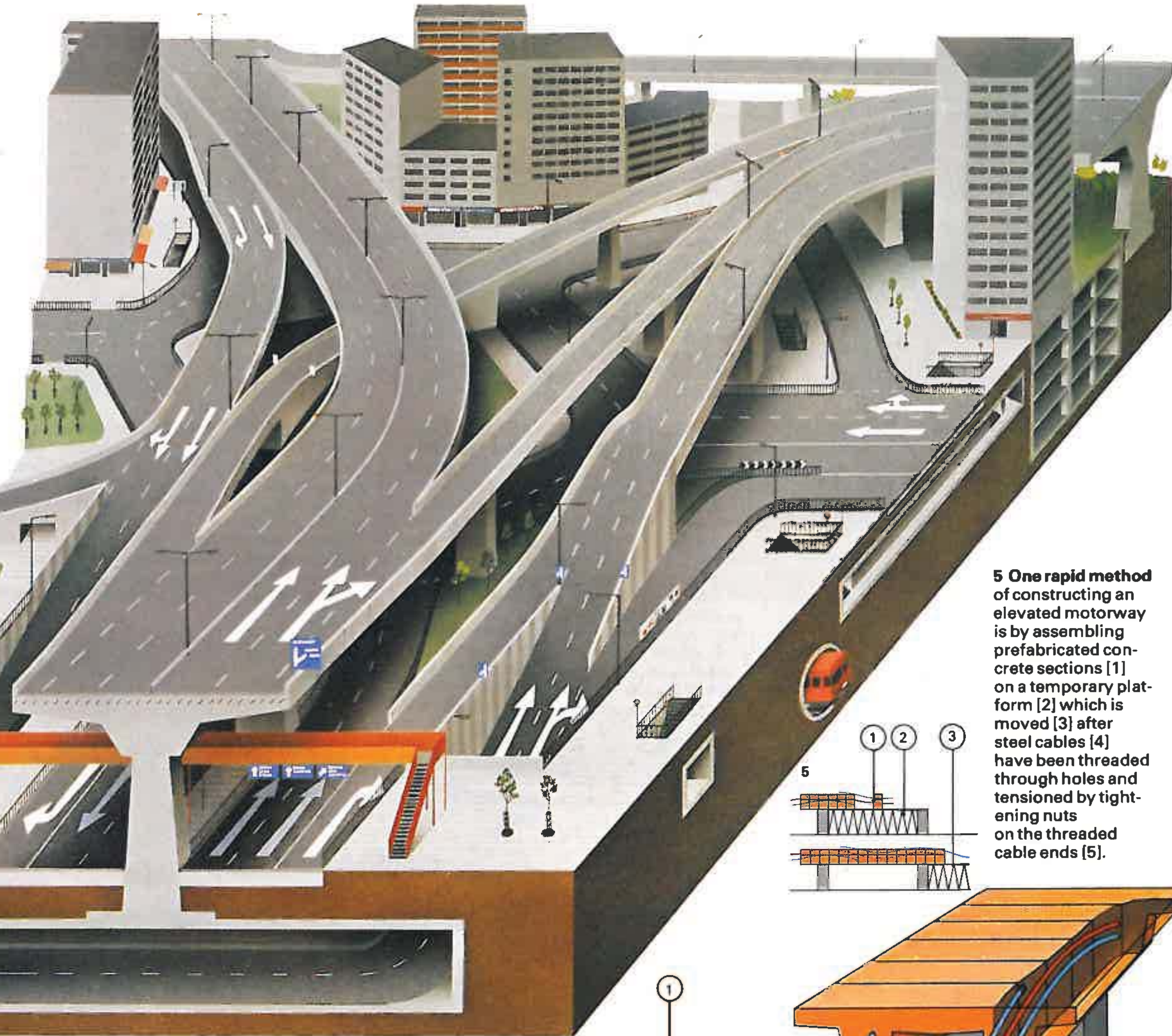
The complexity of traffic engineering increases off the freeway as vehicles seek facilities to stop or park throughout the city. Expedients to reduce congestion include parking restrictions, designation of clearways where no stopping is permitted, bans on U-turns, extensive one-way systems and computer-controlled traffic flows along busy routes. Traffic surveillance with remote-controlled cameras allows rapid identification of trouble spots so traffic can be rerouted or restricted. In many cities, the policy is to reduce private traffic by both the improvement of public transport and the control and restriction of car parking and road use. For example traffic lanes can be restricted to vehicles carrying a specific number of passengers (instead of just the driver). Another possibility is to make direct charges for road use by fitting vehicles with electronic "number plates" that register on road sensors.

KEY



Road signs are intended to help drivers by supplying them with useful information, but there is a danger at busy junctions that too many signs placed close together may be more likely to confuse than clarify, especially at dusk or at night.

4



4 Urban freeways have to be designed within the confines of existing cities. Access points must fit local traffic needs, both in their location and their capacity. As freeways cannot be accommodated in existing cities at ground level (except where an old rail track, for example, is given over to a roadway), they may be built in tunnels or overhead. One of the disadvantages of surface routes and elevated city freeways is pollution of the atmosphere by the high concentration of exhaust fumes in the surrounding area and by the noise of high-density, fast traffic. Overhead roads may also look unattractive or spoil views from existing apartment buildings. Architectural values can be radically affected by the construction of an urban interchange. Complex structures are needed to ensure that traffic leaving a freeway can disperse quickly enough to avoid a build-up of slow traffic on the through roadway. Such structures can often bring increased congestion to the old roads near the freeway exit.

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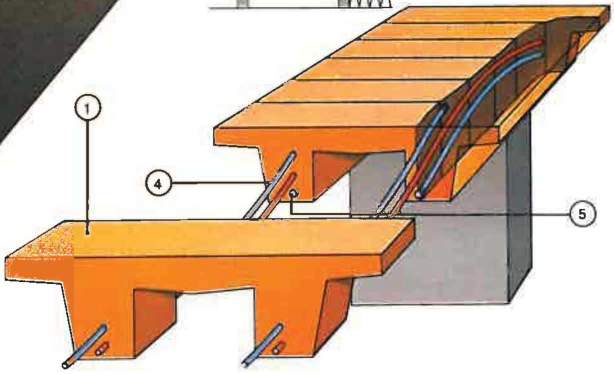

5 One rapid method of constructing an elevated motorway is by assembling prefabricated concrete sections [1] on a temporary platform [2] which is moved [3] after steel cables [4] have been threaded through holes and tensioned by tightening nuts on the threaded cable ends [5].