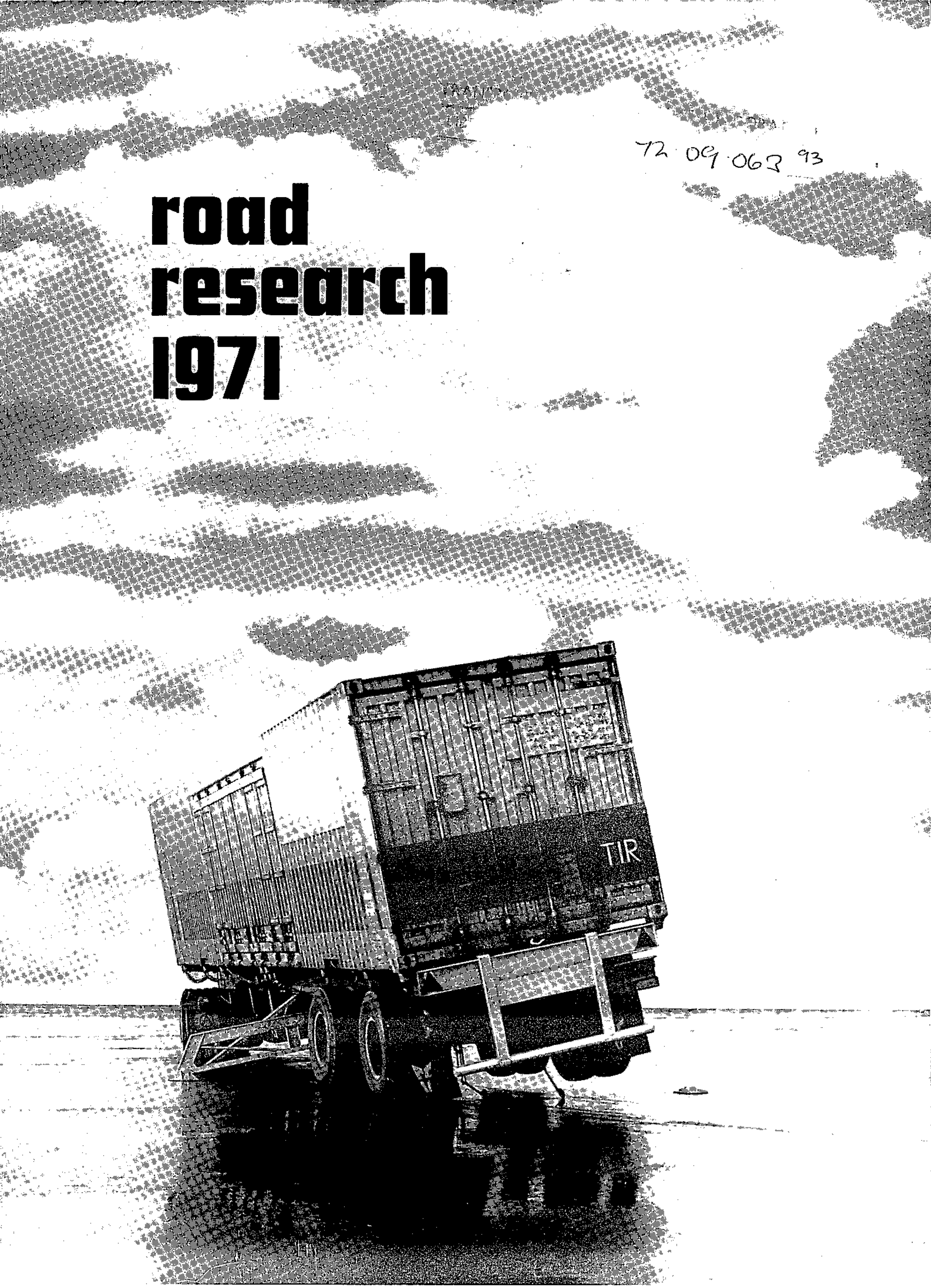
road research 1971



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ROAD RESEARCH 1971

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Articulated vehicle roll stability test
38·5 Mg. Vehicle in roll-over condition.
Section 3.2.3. p. 51.

ROAD RESEARCH LABORATORY
Department of the Environment

road research 1971

Annual Report of the Road Research Laboratory

(Editorial note: The name of the Laboratory was changed to the Transport and Road Research Laboratory on 1st January 1972, but the title Road Research Laboratory (or RRL) has been used throughout this Report.)

LONDON HER MAJESTY'S STATIONERY OFFICE 1972

CONTENTS

INTRODUCTION

For the Laboratory 1971 was a year of transition following its incorporation in the newly formed Department of the Environment. The broad scope of the Department, bringing together Government responsibilities for transport, housing, and local and regional planning, led naturally to an extension in the activities of the Laboratory reflected in the change of name to Transport and Road Research Laboratory, announced by the Secretary of State at the end of the year. For similar reasons a new Headquarters organization was formed to be responsible for the general direction and co-ordination of the Department's research programme; in February 1971 Mr Lyons was appointed Director-General of Research to head this organization, and in June it was my privilege to succeed him as Director of the Laboratory. This Annual Report thus describes work which was, for the most part, started when Mr Lyons was Director.

The Green Paper* published in November, which included the report by Lord Rothschild advocating a 'customer-contractor' relationship for applied research, was an important contribution to the continuing discussion about the proper role of Government scientific establishments. Although—as its name implies—the Laboratory has long had well-defined 'customers', the proposal emphasized the need to restate its principal aims. Briefly these can be defined as providing scientific and technical information and advice to aid the formulation, development and implementation of Government policies for roads and transport, including their interaction with urban and regional planning. The interests and responsibilities of central and local government naturally take account of those of industry, and thus the Laboratory will continue its direct links with local authorities and with industrial firms and other organizations. At the same time, international links, particularly with other European countries, are being strengthened and extended. The procedure established within the Department for formulating and authorizing the programme of work of the Laboratory recognizes these influences: a series of Research Requirements Committees, each dealing with a major policy area of interest to the Department, and with the Head of a Policy or Executive Directorate as its Chairman, is charged with identifying those problems which need research to aid in their solution. It is the responsibility of the representatives of the Research Establishments on these Committees to draft programmes of work designed to meet these needs; these programmes, after discussion and, generally, agreement, are then combined and forwarded to three Programme Review Committees. These three Committees, chaired by the Director-General of Research, are concerned with planning and transportation, building and construction, and environmental pollution and resources, and thus deal with all the Department's research carried out or sponsored by the Laboratory, other Research Establishments, and Headquarters. The programmes are finally submitted to the Permanent Secretary of the Department, and, through him, to the Ministers concerned.

In parallel with this formal Departmental executive committee structure, there are Advisory Committees, with independent as well as official members, to provide advice and guidance, so ensuring that the views of local authorities, industry, and other outside bodies are known when programmes are being formulated. Some changes will be made to the committees advising the Director of the Laboratory, but during 1971 the Research Committees continued as in recent years, with a new Tunnels Research Committee being formed early in the year. In addition, the growing number, range and size of the external contracts placed by the Laboratory to further the research programme also lead to more extensive links with industry and universities.

The aims of the Laboratory are achieved mainly by carrying out research and related activities in highway engineering, traffic engineering and safety, and transportation. In highway engineering the Laboratory is concerned with the planning, design, construction and maintenance of roads and highway structures, particularly bridges and tunnels; the significant changes in this work during the past few years include a greater emphasis on 'life cycle costing' and system studies. In traffic engineering and safety the aim is to develop improved methods for the safe, efficient, and convenient movement of people and goods; this includes work on the layout of roads and transport networks, and the study of methods of reducing the frequency and severity of road accidents. Here the car safety programme, closely related to the international Experimental Safety Vehicle project initiated by the United States Government, is an important new activity bringing the Laboratory into closer contact with the motor industry in Britain. In transportation research the Laboratory will be

*Rothschild, Dainton, *et al. A framework for government research and development.* Cmnd 4814. London, 1971 (HM Stationery Office).

principally involved in examining transport operations and their environmental, economic, social and other interactions with industrial, commercial, residential and recreational activities. Broadly based assessments of existing and projected passenger and freight transport systems, particularly those intended for urban use, are an important aspect of this work. During the next five years it is expected that the Laboratory effort on transport and related activities will increase considerably, largely because of the major economic and social problems of transport and planning, and the growing public concern with environmental pollution due to road traffic and with the conservation of natural resources. As a first step a new Transportation Division was formed in February 1971 ; one section of this Division is the Transport Research Advisory Group which had previously been the responsibility of the Chief Scientific Advisor to the former Ministry of Transport. Further organizational changes will be required to facilitate the next phase of development of the Laboratory.

At the end of 1971 the total number of staff was almost 1000, of whom about 720 were non-industrial categories, including more than 500 professional staff. In addition, the Laboratory continues to attract many guest workers from this country and abroad. This represents a further step in the steady growth of the past few years, and it is hoped that this will continue so that the Laboratory can effectively discharge its growing responsibilities. An important development during the year which affected scientists in Government Service, was the creation of the new Science Group bringing together the former Scientific Officer, Experimental Officer and Assistant Scientific classes. This integration should provide new opportunities for many staff of the Laboratory, particularly in view of the closer links with the new Administration Group. An increase in staff numbers naturally requires further accommodation, and during the year work began on a new bu lding for 150 staff; it is hoped this will be available before the end of 1972. However, it was unfortunately necessary during the year to accommodate temporarily some staff away from the Crowithorne site in offices at Bracknell.

The growth of the Laboratory makes it increasingly important to examine modern management methods to see to what extent they might be valuable to the Laboratory. A small team has been formed to consider techniques of planning research programmes, and contracts have been placed with the Manchester Business School to help in this. Other studies are being made to apply a 'management by objectives' approach to the research programme.

Work continues for the Overseas Development Administration of the Foreign and Commonwealth Office. During 1971 this took up about 8 per cent of the total staff of the Laboratory and included a number of particularly interesting projects, such as those in Cyprus and with the World Bank in Kenya, referred to in a later part of this report. In June, the first part of one of the series of biennial Round Table Conferences on overseas highway problems was held at Crowthorne. On this occasion it took the form of a seminar to present to senior government engineers from developing countries the results of recent work by the Laboratory on transport planning and road building.

The Laboratory provided part of the British Delegation to the 14th World Road Congress organized by the Permanent International Association of Road Congresses (PIARC) in Prague in September, and members of staff serve on several PIARC technical committees. The activities of the OECD Steering Committee on Road Research, and its associated research groups, continued to be supported, and in October an international meeting of documentalists and computer experts was held at Crowthorne at an important stage in the development of the International Road Research Documentation (IRRD) scheme.

Continuing and effective links were maintained between staff of the Laboratory and highway engineers in the Headquarters of the Department and in the offices of the Road Construction Units, of the Chief Road Engineer of the Welsh Office, and of the Divisional Road Engineers. The Projects Officer appointed by the Laboratory assisted in this by visiting the regions and organizing symposia on joints, waterproofing membranes and lighting for bridges, and on the design of road junctions with special reference to the mini-roundabout. Existing direct links with others in Headquarters and elsewhere dealing with road and vehicle safety were strengthened, while active contacts were established by many staff, especially at senior level, with new colleagues in the Department concerned with planning and environmental problems.

A major event during the year was the Open Days held in May, the first since those associated with the opening of the Laboratory at Crowthorne in 1967; they attracted about 15,000 visitors who saw a very wide range of activities on display. These included demonstrations on the track, in one of which visitors were invited to participate; this was concerned with studying ways of loading vehicles on the trains which will travel through the proposed channel tunnel. Later in the year, work on the track included a major experiment on the design of large roundabouts, in which more than 300 members of the public took part, with their cars, for a week.

Distinguished visitors to the Laboratory at other times included The Rt Hon John Peyton MP, Minister for Transport Industries; Rt Hon The Earl Jellicoe, Lord Privy Seal; Mr Graham Page MP, Minister for Local Government and Development; The Rev Lord Sandford, Parliamentary Under-Secretary of State; Sir Roy Jack, Speaker, New Zealand Parliament; Mr Virgo, Transport Minister, Northern Territories Australia; Mr Garnet Brown, Transport Minister Nova Scotia; and The Hon C. S. Stinson, Minister of Communications, Works and Tourism, Fiji.

As in previous years, Part I of this Report is a summary of some highlights of work in progress, and Part 2 contains a more detailed account of research in progress or completed. The order in which the items are described broadly reflects the activities of the Laboratory under the main headings of transportation, traffic engineering and safety, and highway engineering.

A. Silverleaf
Director

AUTOMATED PUBLIC TRANSPORT— A study for an aid to pedestrian movement

One important function of the Laboratory is to study the opportunities for technical innovation in public transport in cities. However, urban transport has so many interactions with city development that relying on new technology as such is seldom sufficient. The more difficult problem is to specify what is required of an urban transport system, taking into account the real constraints of a city, and adapting the technical solutions to these, rather than vice versa.

This kind of 'operational requirement' study must be based on a broad knowledge of the current state of transport technology, and the advances that appear most likely in the near future. The requirements must also be based on an understanding of the tolerance of passengers to physical conditions, for example, vibration and acceleration. This approach leads to a study of transport systems based on a 'scenario' of a real city taking account of the technical and human factor aspects, but paying most attention to the integration of the system into the city fabric.

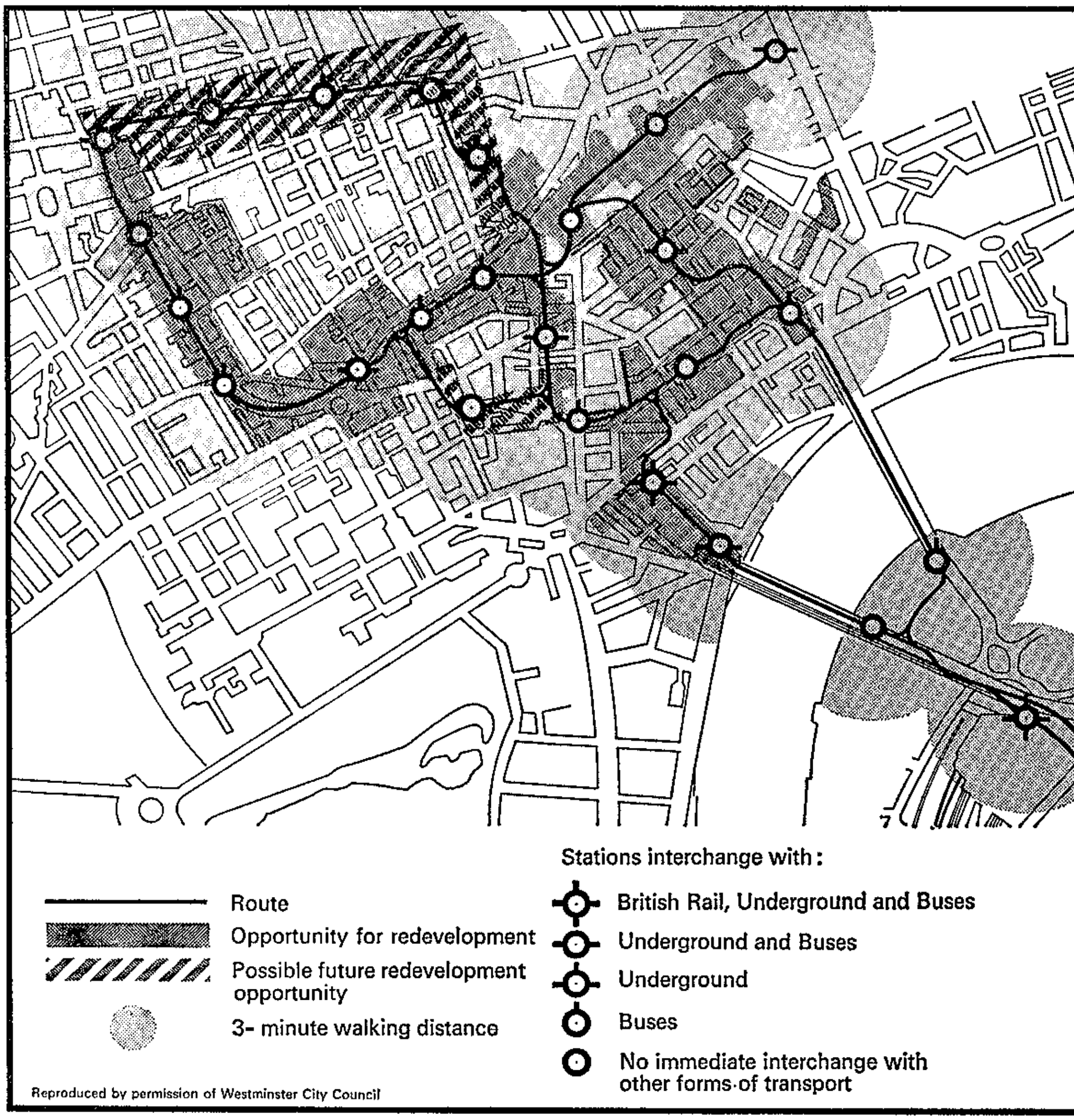
A study of this kind has recently been completed in an area of central London (see Fig. 1). It was made by a Working Group with representatives from Westminster City Council, Greater London Council, and the Laboratory, with assistance from London Transport Executive, and under the chairmanship of the Deputy City Engineer of Westminster. Thus the views of architects, urban planners, transportation planners, and engineers were included, and the result is an amalgam of these diverse interests. The conclusions of the interim study have been published as a public consultation document[1] before formal consideration by the authorities concerned, so that informed public and professional discussion can take place at the earliest stage.

The passenger transport system concept which is described briefly below has become known as Minitram and is similar to proposals and prototype developments which have subsequently been started in America and in Europe (see Section 1.1.1). It is believed to be the first time in this country that a multi-disciplinary group has attempted to define the main characteristics of a system, rather than to choose which of a catalogue of available systems might suit the particular area. This 'customer oriented approach' is one which is likely to be increasingly used in all areas of transport research.

The principal considerations in this particular study, as they emerged in discussion within the multi-disciplinary group, can be summarized as follows:

1. There is a prospect in the West End of London of very substantial redevelopment in the next two decades, extending from Covent Garden to Oxford Circus and having a degree of continuity and comprehensiveness that perhaps only occurs once in a century.
2. The new plans provide for large areas of pedestrian deck, raised to first floor level above the road traffic so as to form, in effect, a new ground level. Hence there is the opportunity of providing for new corridors of movement without the expense of access to an underground system and without interfering directly with existing traffic movement.
3. Space is very limited because of high density of building and high rental values. The transport system would therefore have to be able to negotiate tight curves in order to find a suitable route.
4. Any system would need to be phased in with redevelopment over a number of years, and should therefore be capable of operating, in a limited way, as soon as possible, and be developed with the rebuilding, up to the full network.
5. Because of the high and increasing relative cost of labour, numbers of staff should be kept as low as possible.
6. Large vehicles (like long trains) were judged unacceptable on aesthetic grounds.
7. Service to the passenger should be frequent (preferably continuous) and offered over at least a 16-hour day.
8. The system should be sufficiently light and flexible to be led into major interchanges, and even through buildings (see Figs. 2 and 3).
9. While the characteristics of trips in the area, and other considerations made network cabs[2] unsuitable as a system, it was

Fig. 1
Typical network studied



Reproduced by permission of Westminster City Council

Fig. 2
System routed into Waterloo for easy interchange

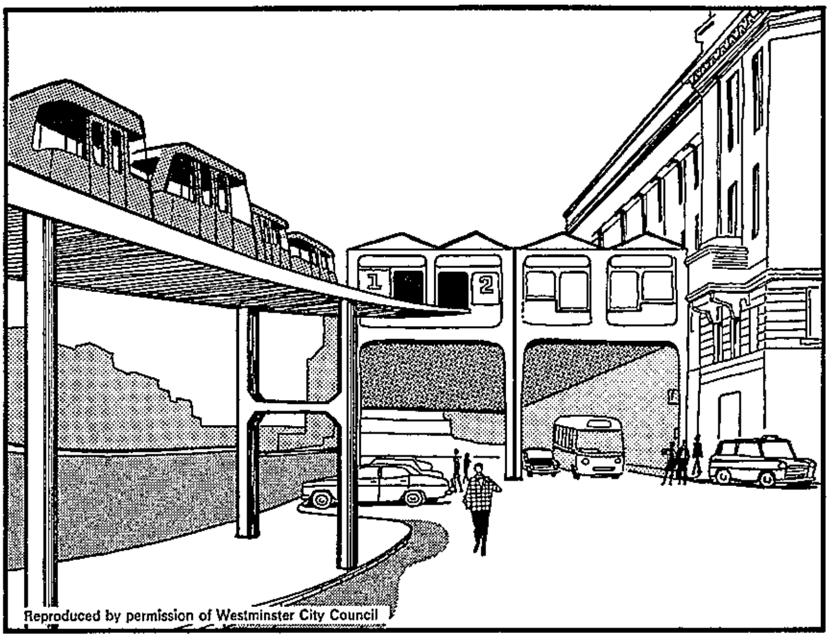
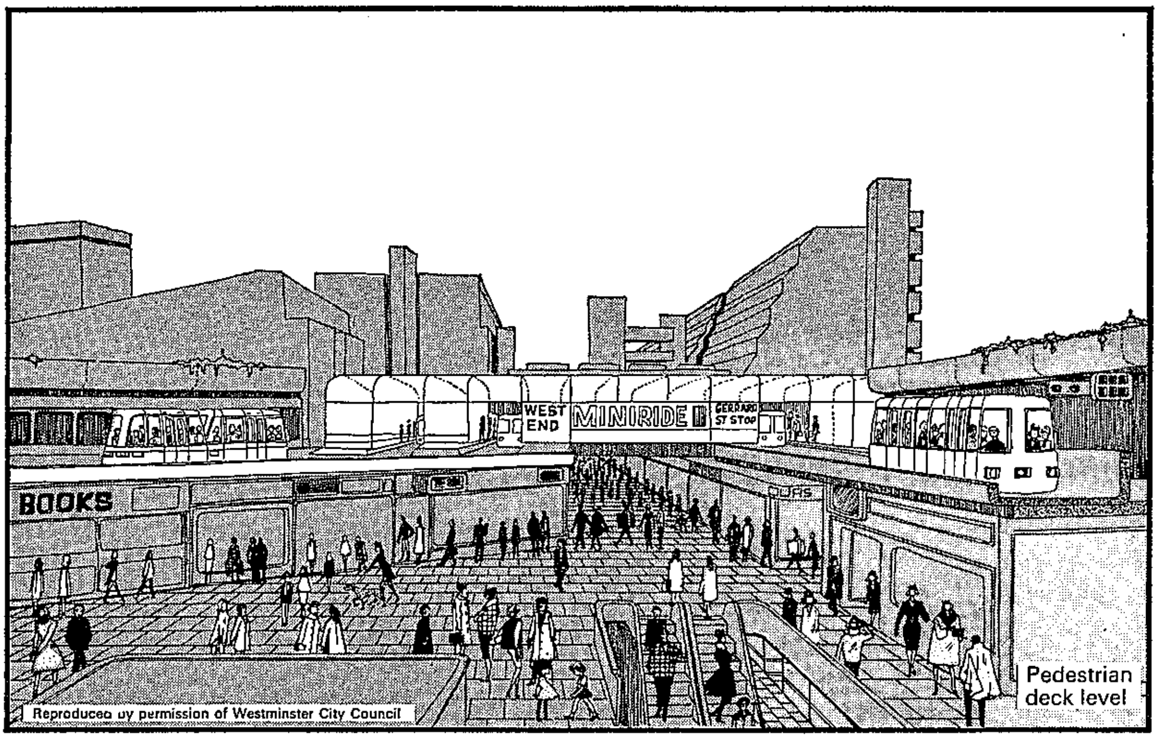


Fig. 3
Scheme integrated in new city development

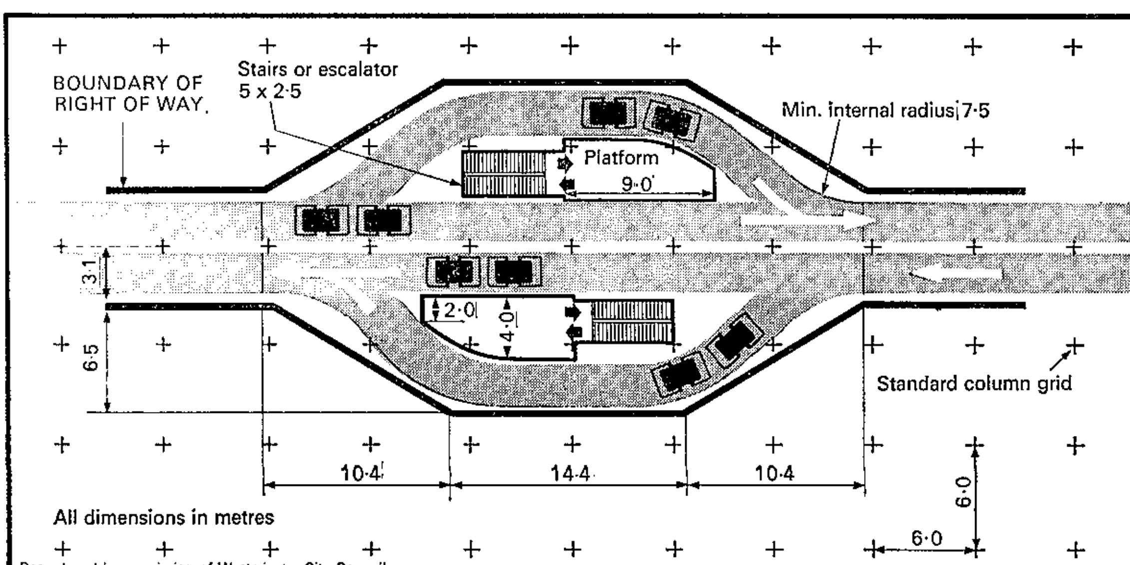


thought useful to ensure that the track was compatible with future development towards a system of this kind.

10. Moving walkways were too slow in their slow speed form and needed too much space for accelerators in the high speed form.

Early in the study it was accepted that an automatic system with vehicles on a segregated track would meet many of these requirements. It was, therefore, natural to consider how automation could be fully exploited. If a vehicle were driverless, it could be run in smaller units without concern for keeping a high passenger to crew ratio. This would lead to lighter structures and be generally more acceptable aesthetically. Entirely new thinking on surveillance, signalling and control from a central computer suggested that headways down to eight seconds could be achieved, provided that the stopping time in stations could be limited to around 10 seconds. This led to a new form of station, shown in Fig. 4, where a loop is incorporated in which consecutive arrivals are switched to alternate sides. This loop would also provide a temporary by-pass facility in the event of a breakdown, and possibly allow the system to be operated on demand when there are few passengers. The short station dwell times can already be observed on existing 'undergrounds' when platform loadings are not too high, and it is reasonable to assume that with short trains, frequent service, and some passenger flow control on platforms, they can be achieved regularly. If they can, and allowing standing room for crush loading, capacity approaching half that for a current underground line may be achieved for much less than half the installation costs of an underground railway. The operating or technical features can be found individually in existing or developing schemes around the world. It is their skilful combination into a new system which could make it effective.

Fig. 4
Station form at mezzanine level above deck



ECONOMIC ASSESSMENT OF ALTERNATIVE POLICIES FOR TRAFFIC RESTRAINT

The possible courses of action to alleviate increasing traffic congestion in towns are becoming a matter of urgency. Practical policies are likely to require elements of broad strategies which include:

1. The introduction and enforcement of regulations.
2. The imposition of parking or road pricing charges to provide a fiscal control on traffic.
3. Road building to provide more traffic capacity.
4. Urban layout to discourage some kinds of road journey and encourage others.
5. Investment in alternative transport systems.

Each of these policies will produce quite different consequences and will lead to wide variations in the total number of trips made, the taxation revenues derived and the overall net benefit. It is therefore worth while constructing a simulation model that will provide a basis for the detailed comparison of the effects of some of these restraint strategies so that the implications may be more clearly seen.

The Road Research Laboratory Transport Analysis Program (RRLTAP) system of model-building programs is well suited to this task, and by applying several of the models in turn the detailed effects on traffic flow and a travel demand may be simulated for most examples of the fiscal and road building strategies. When the different policies are compared by their effect on the same 'present' situation, however, the difference between the economic benefits to be derived will be comparatively small: this requires the model to produce results for the economic assessment that have known limits of error. If this cannot be achieved the comparison of different results could easily lead to incorrect conclusions, as even the ranking of alternatives may be misinterpreted. One of the RRLTAP models used supplies information on size of errors, another simulates the 'present' situation, and a third is used to simulate the effects of the policy to be examined.

The data required for a study of this kind are:

1. A description of the road network in the area of interest and a knowledge of the effect on traffic speed of increased traffic for each of the roads in the network.
2. The number of trips being presently made between the different parts of the area being simulated, and an estimate of the response of the number of trips to increases or decreases in the total cost of making them.
3. The relative importance to the tripmakers of savings in travel time, travel distance, and out of pocket cost, as trips are assumed to be made along paths of minimum cost, generalized to include these features.

The last assumption is the most important: it implies that people will spread their journeys out over the network so as to minimize their own total costs, and if the roads are improved or tolls are charged over any part of the network they will alter their behaviour and thus have an effect on others using the same roads. If a policy is adopted of setting tolls on every road equal to the marginal social cost of each additional user, then, even if the increased cost does not discourage anyone from travelling, it will still be possible to improve the usage of the road network by encouraging people to use more socially efficient routes and thereby make better use of the capacity available on the roads. This effect has been reproduced by the RRLTAP models; the cases of greatest practical interest are those where a 1 per cent increase in cost produces a 1 per cent reduction in the number of trips made. A range of policies have been compared on this basis, and the general deductions that can be made for the ring-radial network used (see Fig. 5)—one typical of a medium sized town at an evening peak hour—are illustrated in Fig. 6. In this diagram the net benefit to the travellers is shown on the vertical axis, and the total amount of new taxation revenue that has to be exacted to achieve this benefit is on the horizontal axis. A desirable policy would give high benefit with low revenue collection.

The main conclusion is that parking charges must be applied over large areas at a comparatively high rate in order to achieve the same effect as road pricing policy. It is also clear that the actual position of a road pricing cordon is critical, and a policy of pricing over a central area is more tolerant to the precise size of the area. It is also clear that parking charges must be set at a higher level than road pricing charges to achieve the same results. This is not surprising as parking charges can only discourage trips that end in a given place and do not restrain the use of roads directly. In particular, road pricing affects through traffic. The variation of fuel taxes shown in multiples of the current rates does not compare favourably with parking or pricing.

It is of particular interest to observe that the building of a new inner ring motorway— simulated here by the uprating of the second ring on Fig. 5, does not invalidate the case for fiscal control of congestion.

These results are indicative of the type of support that these simulation models can give to those searching for policies, as the figures in the diagram are also complemented by detailed patterns of flows and trips. The error bars on the individual points are typical of the limits that RRLTAP shows are attainable in this type of study.

Fig. 5
Circular test network

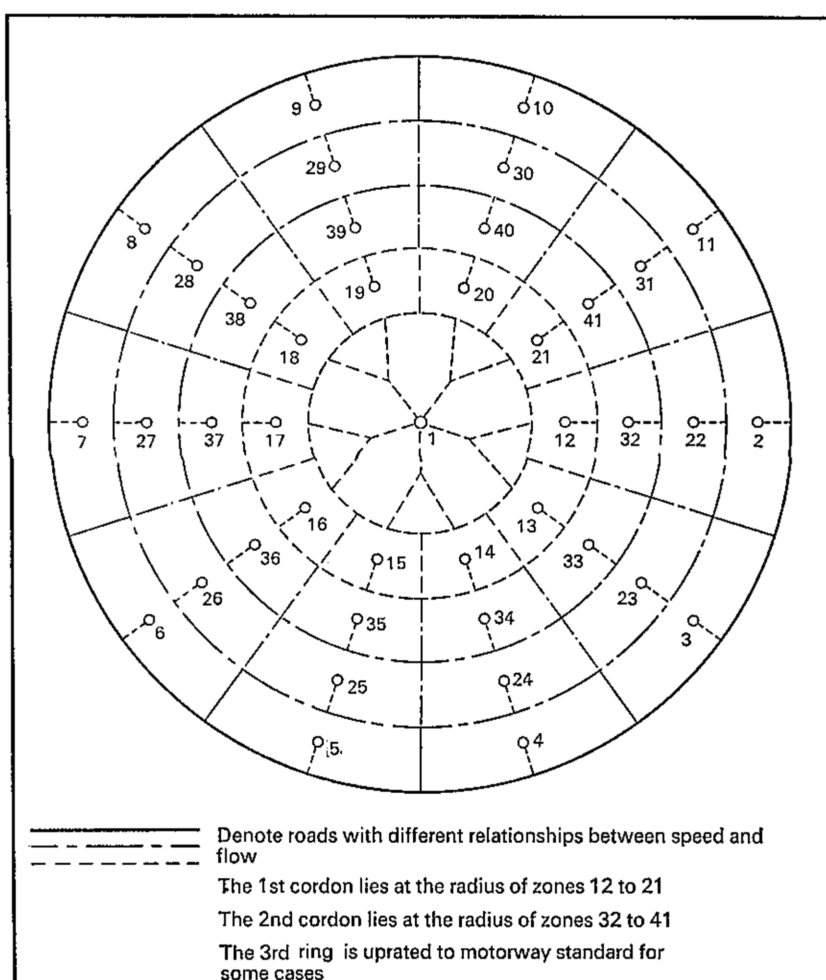
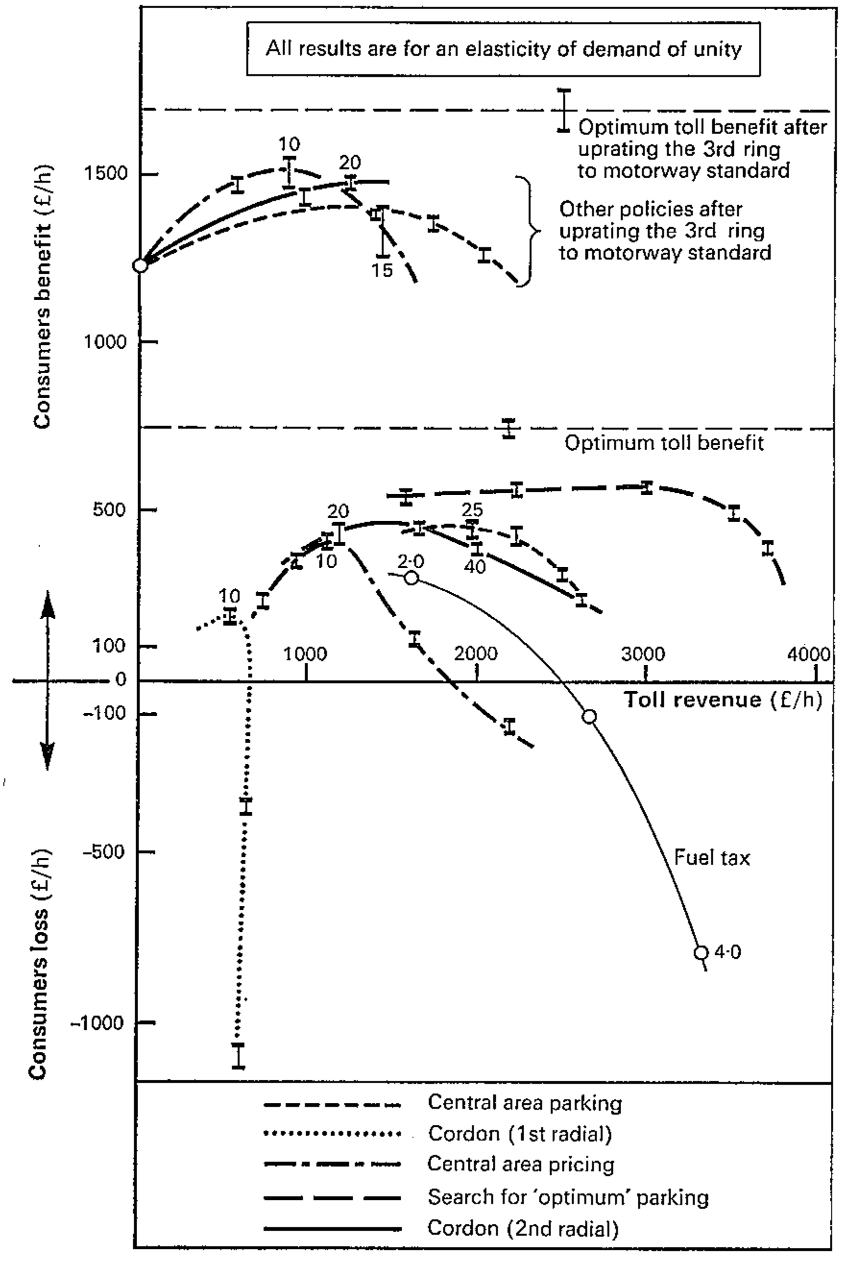


Fig. 6
Comparative effectiveness of a range of restraint policies



TRAFFIC NOISE

Public awareness of the detrimental effects of traffic noise on the environment continues to grow. The Secretary of State has taken note of the recommendations of the Noise Advisory Council that 'existing residential development should in no circumstances be subjected, as an act of conscious public policy, to more than 70 dB(A) on the L_{10} index* unless some form of remedial or compensatory action is taken by the responsible authority'.[3]

Part of the Laboratory's programme directed towards the reduction of traffic noise has been a full-scale noise barrier trial alongside the M4 at Heston (see Section 1.2.1). The barrier experiment was designed in consultation with the Barrier Sub-group of the Working Group on Research into Road Traffic Noise and both the Building Research Station and the Greater London Council Scientific Branch have collaborated in the measurements. The objectives of the experiment are:

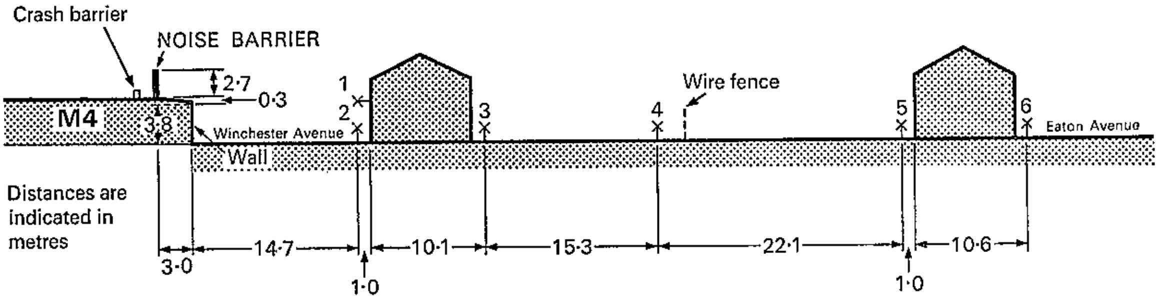
1. To relate the sound reductions obtained with a barrier in a complex urban situation to the reductions predicted from consideration of the performance of an isolated barrier.
2. To investigate public reactions to a noise barrier.
3. To provide a costed trial of barrier construction alongside an operational motorway.

The barrier design was prepared in the Laboratory and incorporates suggestions from the Greater London Council Architects Department. Steel posts bedded in concrete at 2·5 m centres and linked with longitudinal steel channels provide the barrier support. Vertical PVC channels are riveted to the faces of the posts either side of the steel channels and plastic panelling slotted into the PVC channels. The barrier is capped with a plastic strip and the base sealed to ground with no-fines concrete. Plate 1 shows the barrier along the south side of the M4 at Heston. Construction of this 325 m length was undertaken by Hounslow Borough Council and the total cost was £17,000 not including the cost of the existing crash barrier.

Measurements of sound level have been made at various distances from the barrier site with and without the barrier. Figure 7 shows the variation of the L_{10} index observed. The maximum effect was at bedroom window height in Winchester Avenue where the barrier reduced the L_{10} index from 76 to 69 dB(A), i.e. to just under the suggested limit. The levels measured at the Winchester Avenue façade were in reasonable agreement with the levels predicted using the method of Scholes and Sargent.[4] The investigation of public reaction has comprised a survey in the September before construction and a follow up survey in the September following construction. The full analysis of the survey questionnaires has yet to be completed. First impressions indicate that a large proportion of the local residents are troubled by noise. Away from the motorway the complaints are mostly against aircraft noise (the site lies under one of the Heathrow approach paths) but in Winchester Avenue, where the houses face the motorway, traffic noise complaints were predominant in the before survey. Reactions to the barrier are mixed. Many Winchester Avenue residents appreciate the barrier and the reduction of environmental sound level but others claim the barrier intrudes too much on the view from the front of their houses. On the north side of the motorway where there is no barrier some residents have petitioned the Borough for a barrier.

*The L_{10} is the sound level in dB(A) which is exceeded for 10 per cent of the time. Studies have shown that the hourly L_{10}, measured outside houses, averaged over the period 0600–2400 hours, correlates well with human reactions to traffic noise.

Fig. 7
M4 noise barrier—site and effect



Numbers of the microphone sites are 'site numbers'

Site number	1	2	3	4	5	6
L_{10} index without the barrier	76	71	62	62	63	58
L_{10} index with the barrier	69	67	59	61	61	57
Reduction of L_{10} index	7	4	3	1	2	1

CHANNEL TUNNEL FERRY WAGONS

In 1964, the British and French Governments jointly announced their interest in a proposal for a railway linking Britain and France, having previously decided that a rail tunnel was preferable, on economic grounds, both to a road and rail bridge and to continued reliance upon existing means of transport by sea and air. The proposed tunnel would carry both British and French railway rolling stock and also specially designed roll-on, roll-off ferry trains for motor vehicles.

In order that proper assessments of the suitability of some aspects of the proposals could be made the Laboratory was asked by the then Channel Tunnel Engineering Division of the Department of the Environment (DOE) to carry out a full-scale investigation of loading and unloading operations. Primarily, it was required to find how the rate of loading and unloading varied with the geometry of the platforms, side-loaders and carrier-wagons and with the parking procedures in the trains (see Section 4.5).

The Laboratory experiments involved, initially, the construction on the Research Track of a rudimentary representation of a train, using movable pedestrain guard-rails to mark out the wagons; this allowed the dimensions of the wagons to be varied very easily. Members of the public were invited to take part in these experiments using their own cars and, in some cases, towing trailers (boats or caravans). In addition, motor-coaches were hired for the occasion. This preliminary experiment gave quantitative information on the effect of varying the wagon width and the door size of the side-loading wagons on the maximum rates of entering and leaving the train. They indicated that the most restrictive component was likely to be the side-loading wagon. These results, together with considerations of pedestrian movements, structural design problems and tunnel costs, led to the decision to carry out further experiments with a more realistic rig of closed ferry wagons, at the upper end of the range of widths considered.

Two kinds of train were simulated. One was a set of double-decked wagons for cars and other small vehicles (eight carriers plus two side-loaders, 250 m long) : only the lower deck was constructed (Plate 2 left hand rig). The right hand rig (also Plate 2) represented a set of single-deck wagons for all classes of vehicles (10 carriers plus two loaders, 300 m long). The wagon interior walls and roof were realistically simulated by using corrugated PVC sheeting sprayed with aluminium paint (Plate 3). Openings were left for windows and emergency exists.

These rigs were used for an extensive series of tests, partly during the Open Days at the Laboratory so that the reactions of a large number of visitors with their own cars could be tested. The rigs were loaded and unloaded with cars, cars with trailers, coaches and commercial vehicles (including articulated vehicles). The times taken by different mixtures of vehicles to unload and reload trains of various lengths and interior designs were recorded. Forecasts of variability were calculated to indicate the times not likely to be exceeded on more than a certain percentage of future occasions. These times, exceeded only infrequently, are in fact of more importance to designers than the average quoted below.

Generally, a mixture of vehicles would be carried in single-deck wagons.

Pedestrian mobility was also examined in this series of experiments. Some of the tests were simulating movements to amenities, such as vending machines and toilets, whilst others were concerned with the evacuation of the train in an emergency, either along the train interiors or from the trains on to the tunnel catwalk and into the linking tunnels (adits). Pedestrian flow rates and walking speeds were measured at different levels of congestion and with conflicting passenger movements, enabling conclusions to be drawn on such items as the usefulness of one-way walking schemes, the spacing of on-board amenities and emergency evacuation times.

SPEED/FLOW RELATIONS ON SUBURBAN MAIN ROADS

The main results are now available of a major study of speed/flow relations on suburban main roads, carried out by Freeman, Fox, Wilbur Smith and Associates, under contract to the Laboratory with frequent consultation at all stages. Speed/flow relations are used in the economic assessment of road schemes, in the establishment of design standards, and in the construction of mathematical models of traffic behaviour. The results of a study by the Laboratory on rural roads were given in *Road Research 1969*[5], pp. 5 and 31.

Thirteen sections of road with a total length of 50 km, were selected for full speed/flow measurements, involving about 150 hours of observations, early in 1970. Supplementary measurements on a further 13 sections, also totalling 50 km, provided a wider sample of values of the many factors involved. The sections studied were mainly on radial routes in the London, Manchester, and Liverpool areas. Their average one-way width was 6·5 m, 55 per cent of the total length was dual carriageway, and 85 per cent was subject to a 40 mile/h (64 km/h) speed limit. Traffic flows recorded on these roads ranged from 200 to 1700 veh/h per standard lane (3·65 m), and average journey speeds ranged from 15 to 75 km/h. Overall journey speeds along routes 2–6 km long were measured. The speeds of different classes of vehicle—light (three or four tyres), heavy, and bus—were estimated by the moving-observer method, and the corresponding flows were obtained by manual classified counts at a number of points in each section.

Multiple regression analysis was used to relate the speeds of the three classes of vehicle separately to the flow of each class in each direction and to the density of parked vehicles. This showed that the volume of opposing traffic, and the density of parked vehicles found on these roads, had a negligible effect on traffic speeds and could be disregarded in subsequent analysis. While the average speed of the traffic stream was clearly dependent on the proportions of heavy vehicles and buses —since their speeds were consistently lower than those of light vehicles—the speeds of each class were not consistently affected more by the flows of the heavier vehicles than by the flow of light vehicles. All further analyses, therefore, were aimed at relating average journey speed to total one-way flow. To enable results for the various sections to be compared, average journey speeds were corrected to a standard composition (85 per cent light vehicles, 13·5 per cent heavy vehicles, and 1·5 per cent buses), and the flows were expressed in relation to carriageway width. In this form, the speed/flow data could be adequately represented by straight-line relationships, specified in terms of the 'free speed' (the average speed at a flow of 300 veh/h per standard lane) and the 'slope' (the change in speed for a flow increase of 1000 veh/h per standard lane). The same technique was used by the Laboratory in the study of rural roads. No consistent difference was found between the results for peak and off-peak periods.

Formulae were derived which explain as much as possible the variability of the data, without being too complicated. These account for half the variance of both free speed and slope. They relate average journey speed to the free speed and to the total one-way flow, allowing for the effects of dual carriageway sections and the density of major intersections and minor roads.

As might be expected, the density of major intersections is the most important factor, having a considerable effect on both free speed and slope. With no major intersections, the formulae gives a free speed of 63·5 km/h and a slope of −12, whereas with one major intersection per kilometre, the free speed is 53·5 km/h and the slope is −28. These expressions give means of predicting speed/flow relations in the quite complicated conditions encountered on suburban roads.

Weather conditions during observations were included as a factor in the multiple regression analysis, and were found to have a consistent but small effect on speeds. The formulae given here relate to ideal conditions (daylight, dry weather, dry road). The speeds actually recorded (in January, February, and March 1970) were, on average, 0·5 km/h lower than the speeds given by the formulae. During the worst conditions experienced, speeds were 6 km/h lower than in ideal conditions.

CHILD SAFETY

There are several reasons why research into the safety of children on the road is needed: the widespread distress such casualties and fatalities cause, the fact that disfigurement or crippling in childhood can mar a whole life and, not least important, the large number of children involved. In 1969, 737 children (age 14 or less) were killed and 12,918 seriously injured in road accidents other than those in which they were passengers in motor vehicles. There is also a reasonable hope that if improved training and educational measures can be found their effects will persist into adult life and eventually reduce adult casualties.

The Laboratory is working with organizations such as the Royal Society for the Prevention of Accidents to find effective ways and means of reducing the toll. The research can be divided into a number of related aspects; studies of child accidents; studies of the extent to which children are exposed to accidents; and studies of the behaviour of children in possible accident situations. In addition there is research concerned with methods of teaching road safety to children.

The following are some of the facts already known about child accidents:

1. The accident rate for boys exceeds that for girls, the greatest excess being at about four or five.
2. The most frequent age of casualty is between six and seven years.
3. The accident is most likely to occur in daylight and in a built-up area.
4. The younger the child the nearer home will be the accident, most accidents occurring within a quarter of a mile of the child's home.
5. The child is likely to have run into the road and to have been masked by a stationary vehicle.
6. The younger the child the more likely it is to run into or across the road and be masked by a stationary vehicle.

Analysis of detailed accidents reports provided by the Hampshire police has shown that lack of attention is a major factor in child pedestrian accidents and that possibly the role of attention, or its lack, is at least as important as perceptual, judgemental and locomotor skills. Certainly lack of attention on the part of the child in the accident situation precludes the use of any relevant skills. Research is being carried out at universities on behalf of the Laboratory, into the ability of children of different ages to perceive and judge traffic situations in which it is safe to cross. This research, coupled with the accident data and observations of child behaviour on roads, is aimed at identifying unsafe behavioural sequences and is intended to lead to feasible modifications of child behaviour either through training or by traffic engineering. The observations of child behaviour will be related to environmental factors as well as to the personal characteristics of the children involved. The Laboratory is also supporting a study by the Institute of Highway Engineers into the effect of road design features on the occurrence of child and other accidents in residential areas.

Since first issued in 1942 the 'Kerb Drill' has played a large part in the road safety training of children but in recent years there have been some criticisms of it, because of items which it omits, because of ways in which it is sometimes taught and because of research which indicated that children appear to misinterpret it. Research on teaching and training children in road safety at the Laboratory provided the basis for the Green Cross Code, issued in April 1971, which was intended to replace the 'Kerb Drill'. The research team consisted of an HM Inspector of Schools and a Principal Psychologist assisted by a team of trained interviewers and data analysts. The task was first to find out what should be said and secondly how to say it. Finally, some tests on children's ability to use the code were carried out under normal road conditions. Four hundred and thirty-two parents of young children, 277 road safety officers, and 177 teachers were asked by means of a questionnaire to assess the importance, in a crossing code, of items such as 'look for traffic before you cross'. They were also asked how easy they felt it would be to teach these items to a child aged 5–7. The replies of the three groups agreed closely and a clear picture of priorities was obtained.

To find how best to present the most important items, groups of six children aged 5–7 from each of 51 schools were tested at the roadside on their understanding of such words and terms as 'traffic', 'pavement', and 'look all round for traffic'. The schools were sited at different urban and rural conditions and the children covered a range of social backgrounds.

On the basis of this research a simplified wording was adopted for the Green Cross Code which made it more appropriate for children. Finally, the children's ability to follow the Green Cross Code was shown by tests on a total of 160 pupils aged 7–8 drawn from 25 schools, again covering a wide range of urban and rural conditions.

The new code is intended to set out the main principles for safe road crossing behaviour but, of course, it requires the skills of parents and teachers to instil this knowledge into children. A large-scale road safety campaign was carried out by the Department of the Environment to launch the 'Code' and early results suggest that it has been successful in reducing child casualties. Sustained effort will be needed to make further reductions. This first success encourages the belief that continued research in the field of behavioural science will provide the background knowledge for further measures to promote child safety.

CAR SAFETY PROGRAMME

Studies at the Laboratory and elsewhere on vehicles, accidents and injuries have led to a better understanding of the requirements for the design of safer cars. The aim is now to put this understanding to practical use by seeking to develop safety features of car design which can be adopted in commercial production models. This Car Safety Programme is being undertaken in collaboration with the USA and with other European countries. The programme is aimed at developing car safety features in practical engineering forms and incorporating them in complete cars. These can be used to demonstrate and assess the value and cost of the latest ideas on accident prevention and the protection of vehicle occupants and other road users. The Car Safety Programme is being undertaken in collaboration with leading car and component manufacturers.

In Great Britain, the Laboratory has placed contracts for:

1. The development of passive seat belt restraints for car occupants with Auto Restraints Systems Limited.
2. Structural design developments to improve the collapse characteristics of the front and sides of cars and to develop the interior structure and components in accordance with human tolerance levels, with British Leyland Motor Corporation.
3. To develop padding protection and structure for front and side impacts, with Motor Industries Research Association. For investigation of the impact characteristics of materials and components and to evaluate human impact test devices.

In addition, further projects are under active discussion with other manufacturers and research institutes.

ROAD SALTING AND VEHICLE CORROSION

In recent years increasing amounts of salt have been used to keep roads free from ice and snow. This has led to greater corrosion of motor vehicles, and the Laboratory has been investigating the possibility of using chemical additives to minimize the corrosive effects of de-icing salt. Earlier reports, *Road Research 1969*,[5] p. 76 and *Road Research 1970*,[6] p. 83, have described the development of an RRL inhibitor which has been tried in track tests with new British Leyland 1100 saloons. These experiments indicated that the inhibition of corrosion by additives to salt would be a more difficult task than initially envisaged because even the most dilute salt solutions are extremely corrosive. The addition of about 1 per cent inhibitor to salt was ineffective in practice.

In the autumn of 1970 it was therefore decided to evaluate the RRL inhibitor at higher concentrations. Three new British Leyland 1100 saloons were used for these tests. They were strictly comparable between themselves but were not identical with the batch of cars tested previously as a change had been made from 'roto-dip' to electro-phoretically deposited primer. From November 1970 to April 1971 the cars were driven daily through salt splashes and subjected to damage by stone-chipping as described previously.[6] One car was driven through a splash containing 3 per cent brine; the second through 3 per cent brine plus 4·2 per cent RRL inhibitor by weight of salt (i.e. 1260 ppm) and the third through 3 per cent brine plus 7·2 per cent RRL inhibitor (i.e. 2160 ppm). At the end of the winter there was a noticeable difference between the cars driven through the straight brine and the inhibited brine. It is not possible to make numerical comparisons at this stage but, as Plates 4 and 5 show, the corrosion on the car driven through the splash containing 7·2 per cent inhibitor has suffered about half the damage of the one driven through the straight brine. The car driven through the splash containing 4·2 per cent inhibitor is in an intermediate condition.

The general use of the RRL inhibitor at a concentration of about 7 per cent would increase the cost of salting by about £23 million per annum in this country. (Based upon using about 1·5 teragrammes of salt per annum and the inhibitor adding £15 per ton of salt).

The cost of motor vehicle corrosion is not known precisely, nor the proportion of it due to salt. However, the Automobile Association has stated[7] that the annual cost of corrosion per car in Britain is £20, i.e. an annual cost of £260 million per annum for the 13 million cars in Britain. Palmer[8] has found that for the Metropolitan area of Minneapolis, USA, the corrosion due to salt is about half the total, and the RRL survey made in 1967[9] gave a similar proportion for UK conditions. On this basis salt is causing about £130 million per annum of damage in Britain and, if the general use of the RRL inhibitor halves this, the saving would be £65 million per annum. The net benefit would thus be substantial and would be increased by any reduction in corrosion of commercial vehicles.

The results of this research pose two questions. First, would the savings to vehicle users justify the expenditure of an extra £23 million per annum from public funds on winter maintenance of the roads? Secondly, could an extra sum of this magnitude be spent more effectively to reduce corrosion by other means, such as regular washing of the undersides of vehicles, or improved corrosion protection for the vehicle bodies and other components, in particular silencers, replacements of which have been estimated to cost £85 million per annum.[10]

To help answer the second question tests at the Laboratory are planned in which the RRL inhibitor will be applied regularly through a car washing plant. Improvements in some aspects of vehicle protection will also form a part of a co-operative programme with British Leyland.

RURAL HYDROLOGY ROAD DRAINAGE SYSTEMS

When a new road is built culverts and bridges have to be provided to cross waterways. The size of these must be determined by some maximum flow, usually termed a flood, from the upstream catchment for a given return period. If the culvert or bridge is too large costs are unnecessarily high: if they are too small there is a risk of flooding. Present methods of flood flow prediction are either too simple and hence inaccurate, or are extremely detailed, requiring information which is often not available without exhaustive and lengthy enquiries.

The Laboratory has produced a method for estimating flood flows from ungauged catchments in Britain using information which is readily available, the method being based on several year's study of the hydrological behaviour of several natural catchments. These catchments were instrumented to provide continuous records of rainfull and run-off from which individual hydrographs and their associated rainfall were abstracted for analysis. For these catchments, quantity of rain (millimetres or inches) is the most important rainfall factor producing the flood flow (i.e. the peak rate of run-off minus base flow) and that for a given quantity of rainfall the peak rate of run-off is higher in the winter period because soil moisture is at a maximum and evapotranspiration is small.

As can be seen from Fig. 8, there is, for the winter period for each catchment, a linear relationship between rainfall quantity and flood flow; this holds over a wide range of rainfall intensities. In this linear relationship the ratio flood flow to rainfall quantity has the dimension area divided by time. The area is the size of the catchment and the time if considered to be a 'time of concentration', i.e. the time taken from the start of rainfall for all the catchment to contribute run-off to the hydrograph rise. The time of concentration thus defined can be calculated for any catchment and is related to two dominant catchment features, measures of slope and catchment length, which can be readily determined from an Ordnance Survey map. Thus, the flood flow during the winter period for a given catchment is given by a function of area, time of concentration and rainfall quantity.

The method of prediction involves the choice of a return period and the calculation of the corresponding flood flow. This is done by finding for the chosen return period the quantity of rainfall associated with the time of concentration by using a suitable formula. However, as the time of concentration is usually longer than the actual durations of rainfall, the peak rates of flow so calculated have to be corrected by a factor based on the average annual rainfall.

The method of prediction derived from the catchments studied has been tested on seven other catchments each with a similar underlying stratum to that of the experimental catchments, which is basically clay. Figure 9 shows the comparison between calculated and observed peak rates of flow for two of the seven. It can be seen that the agreement is very good. In addition comparisons were made for five catchments having only thin soil over rock. Again there is good agreement between calculated and observed values. A simple modification to the method enables it to be applied to catchments with appreciable permeable strata such as sand and gravel. In all, 20 catchments with areas up to 115 km^2 and times of concentration of up to 65 hours have been tested satisfactorily. A full account of this work together with the results of 16 of these catchments is given in a Laboratory Report.[11]

It is emphasized that the method is for the calculation of peak rates of flow and it is not intended for the calculation of complete hydrographs.

Fig. 8
Flood flow against quantity of rainfall

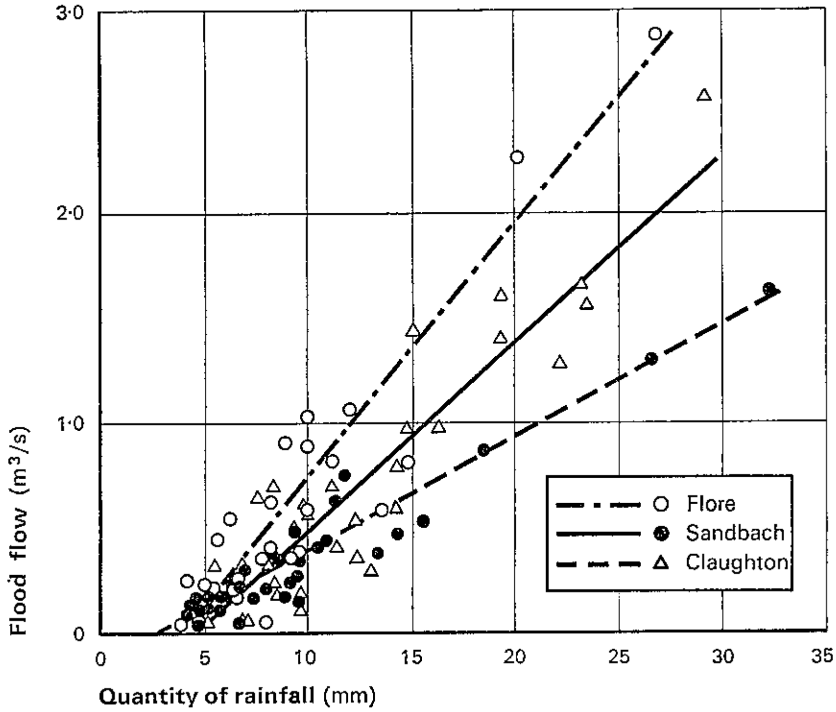
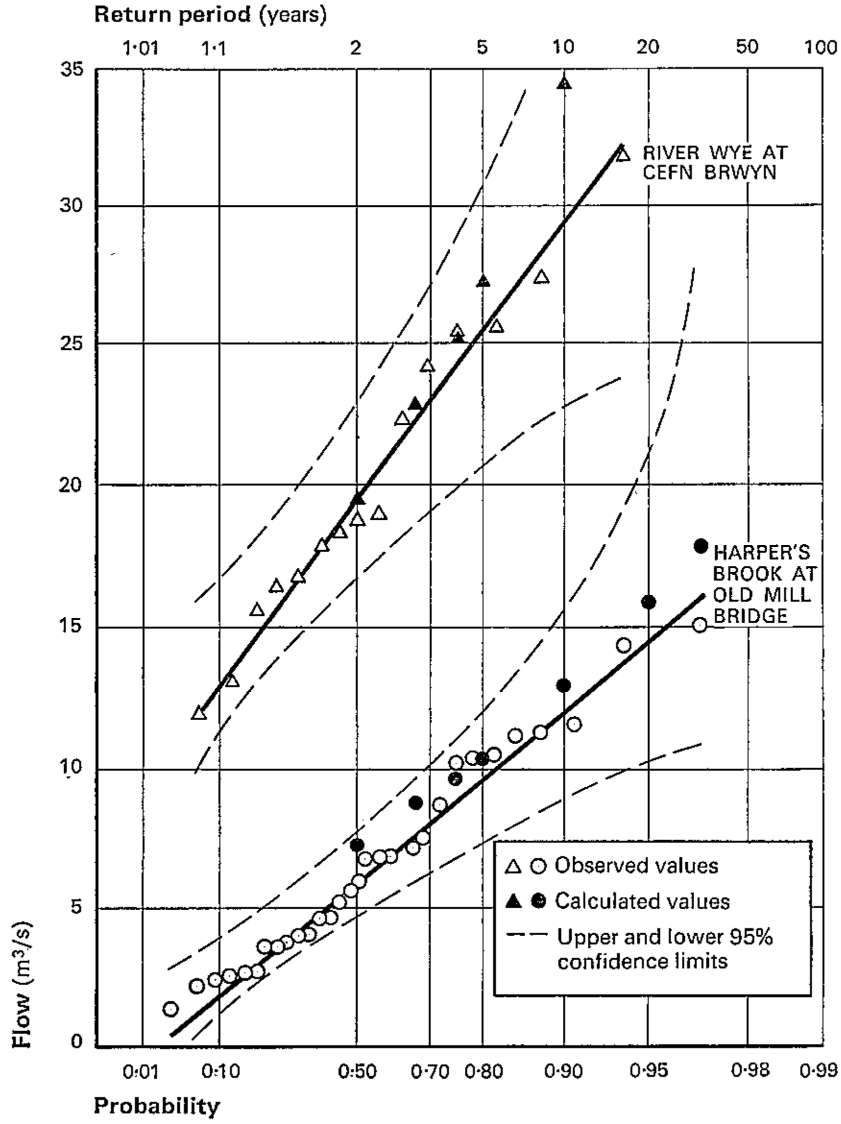


Fig. 9
Comparison between calculated and observed peak rates of flow for two test catchments



ACCELERATED METHODS OF TESTING CONCRETE

Accelerated curing of concrete. The quality of concrete is normally specified in terms of its strength 28 days after manufacture. In this period an appreciable proportion of the ultimate strength of the concrete is developed and the test therefore gives a reasonable estimate of the final quality of the concrete. The basic disadvantage of this practice is that the placed concrete will also have developed considerable strength and, in the case of structural concrete, will probably have been covered by later stages of construction before its quality can be judged against the specification. In practice, on the majority of construction sites the production of concrete is completed within the period of 28 days. Failure to meet the specification can therefore involve tardy and expensive remedial measures.

If the quality of the concrete could be determined at an early age it would be easier to carry out any remedial measures on unacceptable concrete, a smaller volume of concrete would be at risk at any one time, and the early feedback of results would provide a basis for better control of the concrete production.

A variety of different methods have been developed to accelerate the maturing of control specimens in order to enable an early assessment of the quality of the concrete to be made. The Institution of Civil Engineers formed a committee to make a comparative study of these methods and, after a series of cooperative tests by six laboratories in 1968, the Committee recommended for use a regime based on a period of 24 hours' immersion in water at 55 °C, as this gave the most consistent results. Following certain reservations that were expressed on the practicability of the time tolerances in this regime, further laboratory studies were carried out at RRL and some modifications were recommended to make the regime more convenient for use on construction sites (see *Road Research 1970*,[6] p. 106).

Recent studies at the Laboratory have concentrated on factors which could affect the interpretation of the results of the test. The relation between accelerated and 28-day compressive strengths is significantly affected by the incorporation of entrained air, but different types of aggregate and sources of ordinary Portland cement have little effect.

As the cylinder-splitting (indirect tensile) test is now specified for assessing the quality of pavement-quality concrete, correlations were also sought between accelerated and 28-day indirect-tensile strengths. Results showed that the relation was influenced by the type of aggregate, although the incorporation of entrained air had little effect. In general, the indirect-tensile strength is accelerated to a greater proportion of its 28-day value than is the compressive strength. Further work will be carried out on the effect of different types of admixtures and on lean-concrete mixes.

To assess the suitability of accelerated curing techniques for site operation, a test programme was devised in which both Laboratory personnel and staff from a testing consultant were employed to carry out the concrete testing on a large motorway contract in the Midlands. The testing programme included comparisons of the accelerated and normal 28-day curing techniques when applied to cubes and cylinders and also provided information about the breakdown of the overall variability into its various components, i.e. production, sampling and testing.

No difficulty was experienced in employing the RRL accelerated curing regime under site conditions and a preliminary statistical analysis of the data obtained has shown no detectable difference between the patterns of results obtained by the consultant's and the Laboratory staff.

There was a significant reduction, at the 5 per cent level of probability, in the total variability of the compressive-strength measurements on cubes subjected to accelerated curing when compared with 28-day cured cubes (see Table 1).

The main contribution to the total variability of the compressive strengths was associated with the production process; this was most marked for the specimens subjected to accelerated curing. The remaining variability was due to testing, which will include any contribution from curing, there being no significant contribution from sampling (see Table 2).

A relationship was found between the daily means of the compressive strength measurements on cubes which had been subjected to accelerated and 28-day curing. The relationship is shown in Fig. 10 and is in broad agreement with the findings from Laboratory investigations.

Table 1 : Comparison of total variabilities of strength measurements on accelerated and normally cured cubes

Curing	No. of results	Mean strength	Variance	Standard deviation
Accelerated	240	25·41 MN/m²	10·08	3·17 MN/m²
28-days	160	46·06 MN/m²	15·85	3·98 MN/m²

Table 2: Main contributions to the overall variability

Curing	Testing variance	Production variance	Total variance
Accelerated	0·55	9·53	10·08
28-day	3·75	12·06	15·81

Specimens subjected to the indirect-tensile strength test after accelerated curing were significantly more variable than those cured by the normal procedure, but the available data summarised (see Table 3) is known to be limited in scope.

Table 3: Comparison of total variability of indirect tensile test specimens after accelerated and normal curing

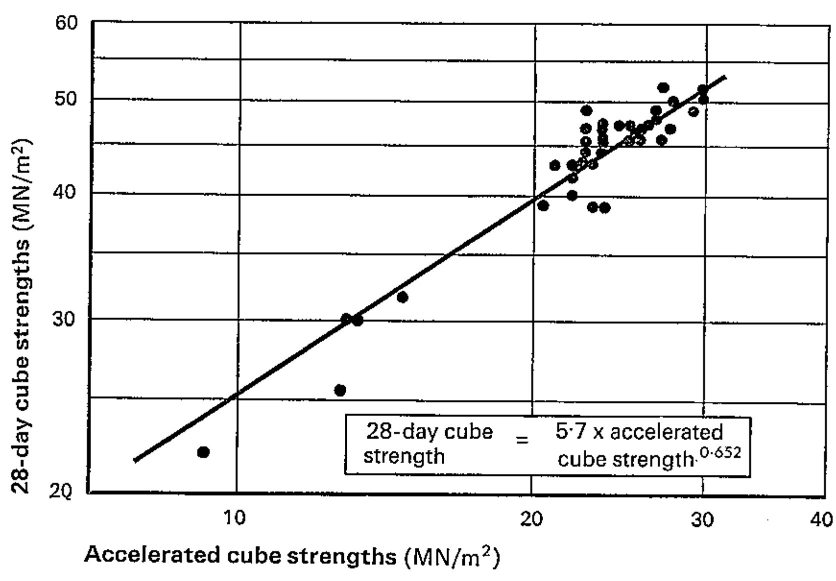
Curing	No. of results	Mean strength	Standard deviation
Accelerated	80	2·18 MN/m²	0·363 MN/m²
28-day	80	3·33 MN/m²	0·232 MN/m²

The results of this work are now being considered by a Committee of the British Standards Institution, with the aim of producing an agreed technique for incorporation in BS1881.[12]

Rapid analysis of concrete. At present, the day-to-day control of concrete production and the on-the-spot acceptance of concrete supplies as being suitable for laying, depend very largely on some measurement of workability, and on a visual examination of the material. As already described, indication of the potential strength of the concrete can be obtained one day after mixing by using accelerated curing techniques. At the same time great interest has been shown in the development of rapid analysis techniques which provide information about the composition of the concrete mixes within about 30 minutes of their discharge from the mixer.

Apart from the obvious advantage of an early indication that the output of a plant is under control, there will also be a need for this type of method for the determination of cement content to judge the acceptability of concrete if a minimum cement content is introduced into specifications. The only rapid method of analysis of concrete that has been used to any great extent is described in BS1881 :[12] this method, based on a physical separation of the aggregate from the mix followed by weighing under water, has never gained wide support because of the need to carry out preliminary tests on the raw materials and then to apply

Fig. 10 Relationship between accelerated and 28-day cube strength



correction factors to the values obtained from the analyses. In practice, it has not proved easy to obtain reliable results although, with experience and a sympathetic understanding of the detail of the method, it is possible to use the method most effectively, especially when the aggregate supplies are consistent. The Scientific Branch of the Greater London Council and the Research and Development Department of the Laing Construction Company have both developed new rapid methods of analysis of fresh concrete to meet their own particular requirements and to overcome the criticisms of the standard procedure. Both methods consist basically of sieving out the cement and fine material (passing either 300-micron sieve or 212-micron sieve). In one case, the cement is then estimated photometrically and in the other by flotation-separation. Other constituents are estimated by conventional dry sieving.

Site trials of both methods by the Laboratory have shown that each takes about 30 minutes to perform. The Laing method uses more robust apparatus and may be more suitable for use under site conditions. It gives more reliable cement contents than the GLC method but a more variable estimate of water content.

The Laing method was chosen for further study to estimate precision; in this work the Building Research Station, the Cement and Concrete Association, John Laing Construction and Development Limited, the Amey Group and Ready-Mix Concrete Limited collaborated with the Laboratory in a series of tests, in which a fairly wide range of concrete mixes have been analysed including some of the most difficult materials, to provide a critical examination of the test procedure. The results from this research programme are at present undergoing statistical analysis to establish the repeatability and the reproducibility of the test procedure. This information, together with other points revealed by the tests, will be submitted to the appropriate Technical Committee of the British Standards Institution.

ROUND TABLE CONFERENCE ON OVERSEAS HIGHWAY PROBLEMS

The 10th Round Table Conference on Overseas Highways Problems was held on 9–11 June 1971. This Conference is organized jointly by the Laboratory, the Overseas Development Administration of the Foreign and Commonwealth Office and the Institution of Civil Engineers. It provides a forum at which members of the Highway Departments of the governments of developing countries review current problems in the planning, design, construction and maintenance of roads. The 1971 Conference was attended by 20 delegates from 13 different countries. Also present were representatives from the World Bank (International Bank for Reconstruction and Development), the Crown Agents, the Caribbean Development Division, Land Resources Division and Overseas Development Administration of the Foreign and Commonwealth Office.

The first two days of the Conference were held at Crowthorne and took the form of a seminar to discuss the research carried out by the Laboratory on overseas highway problems. The final discussions were held at the Institution of Civil Engineers.

Among the subjects discussed particular interest centred on:

1. The design of bituminous overlays as a method of strengthening and prolonging the life of roads. This was particularly related to the use of pavement deflection measurements to establish the residual strength of roads in relation to the cumulative total of equivalent axle loads.
2. The life of surface dressings. There are large variations in the lives of surface dressing in different parts of the world. These may range from three to ten years at similar traffic levels and the discussion centred on the probability that this variation results from the quality of workmanship. The need for demonstrations to improve the skill of operatives was discussed.
3. The use of labour intensive techniques in road construction. The creation of jobs is being considered as an important criterion in investment in developing countries and road construction appears to offer opportunities for the use of labour intensive techniques instead of the more usual capital intensive operations. This may mean looking afresh at the design and construction standards. Although considerable doubt was expressed as to whether it was feasible to carry out complete projects on a labour intensive basis there were almost certainly some operations that could adequately be carried out using either entirely manual or some intermediate form of technology.
4. Training overseas engineers. Great interest was shown in the opportunities for highway engineering training with particular relevance to the problem of developing countries. It was felt that this was required at both professional and subprofessional levels. The Laboratory already takes a limited number of technicians as voluntary workers for training at Crowthorne and it is intended to place this scheme on a more formal basis. The possibility of establishing a post-graduate MSc course in highway engineering for overseas conditions is being actively investigated.

Part Two: Summary of work on current research
1. TRANSPORTATION DIVISION

1.1 Transport Research Assessment Group

1.1.1 Introduction
The Transport Research Assessment Group (TRAG) was formed in September 1967 as a consortium of engineers and scientists from several government research establishments to 'assess the need for additional research and development for transport in relation to future requirements and demands, to evaluate proposed systems, and to make recommendations to the Joint Transport Research Committee'.[13] The Research Committee was a joint organization between the then Ministries of Transport and Technology, with representation from other bodies including NRDC, United Kingdom Atomic Energy Authority and British Rail. The research programme for TRAG has been the responsibility of this Joint Research Committee (JTRC). The Group though located at RRL Crowthorne was not formally a part of the Laboratory until February 1971 when the Transportation Division was formed, and TRAG became part of that Division.

TRAG consists of about twenty scientists and engineers drawn from RRL, RAE Farnborough, AWRE Aldermaston, and other organizations, although the majority are from RRL. The assessment work, which is its major task, is often the subject of restrictions on publication because of the commercially useful information which results from it. However, some indication can be given of the main topics on which TRAG has been engaged in the last year. A description of work on a form of automated public transport (Minitram) has already been given in Part One p. 1, and in the following sections work on new transport systems is described, together with an application of computer techniques to an operational problem (bus crew scheduling) and a development of assessment methodology (travel demand mapping).

1.1.2 Pedestrian conveyor studies
Pedestrian conveyors offering high passenger-carrying capacity and a 'no waiting' service have attracted inventors for nearly a century. Renewed interest, reflected in increased research and development, has occurred in recent years, arising from increasing concern about the consequences of expansion of existing transport modes, including such aspects as increased congestion in cities, atmospheric pollution and noise.

Although the number of pedestrian conveyors installed annually for public transport service is increasing, all systems installed to date have an operating speed of about half walking speed and it would appear logical to seek to extend into the use of high speed conveyors (up to 16 km/h) if the human capability and technological problems could be identified and solved. One of the many possible approaches is the design being developed by a joint Dunlop/NRDC Company, which should result in a practical demonstration of a particular kind of 'accelerator' to enable the passenger to be taken from walking up to a higher speed.

However, even in this solution there may be unresolved problems of passenger safety and tolerance to motion.

The Transport Research Assessment Group therefore initiated two research projects covering the problem areas.

The Human Engineering Division of RAE Farnborough carried out a series of experiments to determine passenger response to various levels of acceleration and rate of change of acceleration (jerk). Passengers taking part in these experiments were selected to reflect a cross section of the travelling public in age, sex, physical capability and degree of impediment to normal movement afforded by hand luggage, child supervision, and group movement (Plate 6). Further experiments sought to determine an appropriate transfer time between two sections of a device moving at different speeds. Deductions were made concerning the relationship between time for transfer, relative speed between the two sections of the device, and the total length of available interface required to complete a safe transfer.

Under a parallel contract, the United Kingdom Atomic Energy Authority carried out a survey and engineering assessment of all systems or devices which could be found. The extent of the information available in each case varied from simple provisional patent applications to detailed data from operational systems. This work necessarily involved collaboration with, and assistance from, several industrial companies, transport undertakings, universities, and private inventors in Britain and abroad.

The objects of the survey and assessment were to identify the more practical proposals and to identify and investigate basic technological parameters to provide basic systems data (e.g. capital and running costs, overall dimensions, etc.). The information from the above work provides some of the input necessary to assess the feasibility and economic viability, in social terms, of the use of pedestrian conveyors in practical situations. This work is currently in progress.

1.1.3 Small automatic vehicles

Since 1968 an engineering team at the RAE has, under contract to TRAG, made a feasibility study of small automatic vehicles for urban passenger transport. The system most extensively studied is a network cab concept called Cabtrack.[14] Unlike the Minitram system (described in Part One p. 1) Cabtrack provides transport on demand for individuals or small groups between any two stations on the network, without stopping at intermediate stations. Cabtrack would consist of four-seat electrically powered cabs, carrying passengers at 30–50 km/h along a network of segregated tracks under automatic control. The stations at which cabs could be boarded or left would be off the main line so that cabs wishing to stop would not impede the through traffic. Such a system would be suitable for an area of perhaps 5 km × 5 km having a demand for trips of about 2–3 km from many origins to many destinations.

This study has investigated methods of controlling a Cabtrack network and recommended a control hierarchy consisting of three levels: slot following in individual cabs, for headway; individual junctions and stations for headway monitoring, and for switching and merging commands; and network, for changing routine lists at local computers in the event of congestion or emergency, and to limit the use of the system to prevent over loading at peak times.[2]

The control concept has been tested by the digital simulation of single junctions, of single stations of several designs, and of a complete network of six loops of track, 72 stations, 60 junctions, and 4000 cabs. A typical result of one simulation is the variation of the probability of a cab failing to make a desired turn at a junction as the proportion of slots on the main track occupied by cabs is increased (see Fig. 11).

A battery powered test vehicle has been running on a 200 m loop of track since 1970 to test the cab suspension and switching systems (Plate 7). A double loop of track has been built to one-fifth scale and the operation of up to 10 cabs under the control of a Honeywell 316 computer is to be demonstrated during 1972.

The cost of the structural components of Cabtrack and the visual impact of the system on a portion of London has been analysed for TRAG by Robert Matthew, Johnson-Marshall, and Partners.[15]

Economic analyses of Cabtrack from the operators' standpoint have been made by RAE, and a cost-benefit analysis of Cabtrack in London by TRAG. The latter studied a number of central area distribution networks. The predicted diversion of passengers to Cabtrack from other modes is shown in Fig. 12, and it would be necessary during peak hours to charge Cabtrack fares that were approximately double those on buses and underground trains to avoid overloading the system, which would lead to queues and delays. Rates of return depended on cab occupancy, but were probably between 8 and 12 per cent for the system used as envisaged, and up to 20 per cent if cab sharing was used to increase occupancy at peak times.

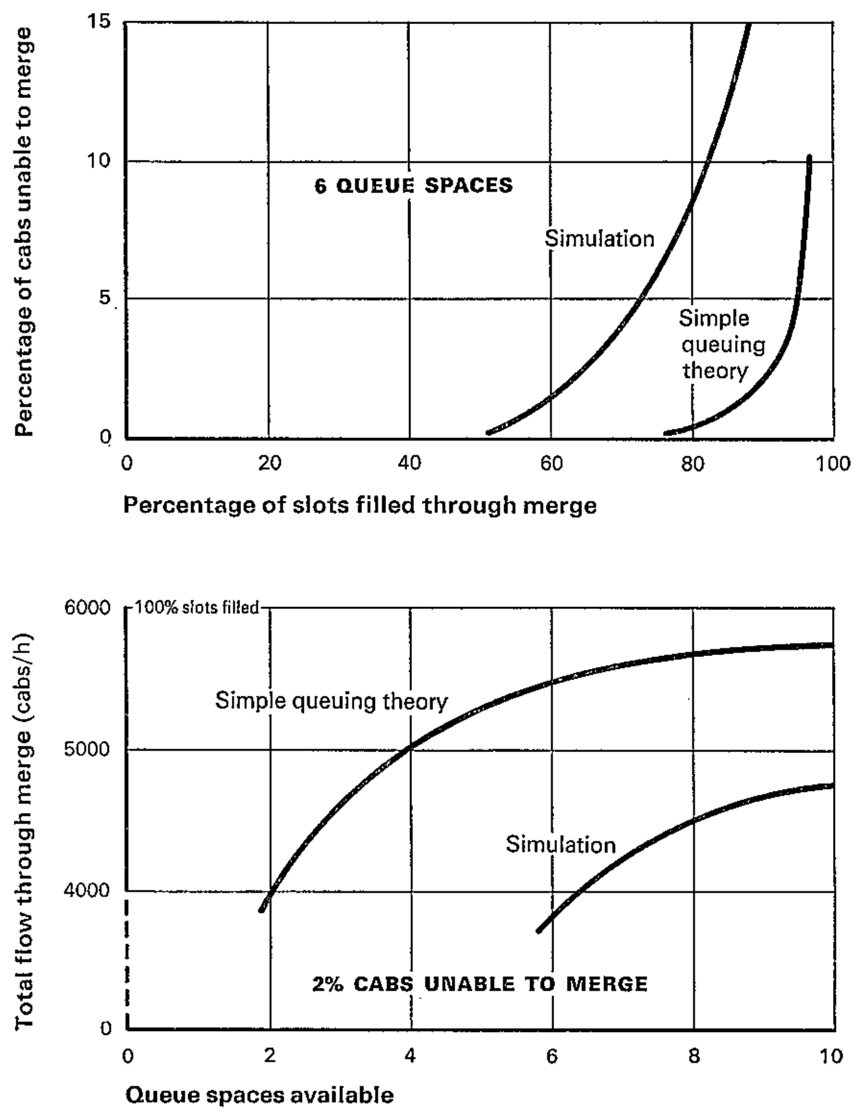
During 1971 the study has been directed towards systems like Minitram using larger vehicles in a shared mode, as these appear to be more suitable for the initial installations which are likely to be in relatively small areas which do not justify the full sophistication of a network cab system.

1.1.4 TRAG assessment of URBA, a French tracked air cushion vehicle

URBA is a transport system at present under development in France by a consortium of companies. It consists of 'monorail' vehicles suspended by suction air cushion from an overhead track and propelled by linear induction motors.

Different sizes of vehicles have been proposed but the system studied was a medium capacity version based on 30-passenger vehicles which could be operated singly or in trains. This version would have a maximum speed of 72 km/h and a transport capacity of about 7000 passengers per hour. The system is intended for urban applications. Alternatively it could be used, for example, to provide a shuttle service between airports or from an airport to a city terminal.

Fig. 11
Simulation results for the flow of cabs through a junction at which static queuing is allowed



The French authorities are planning to operate a prototype vehicle on a test track during 1972 and 1973 and to have the system in operation on a 4·5 km length of track in the city of Lyons possibly by 1974.

An engineering study, which was part of a more general assessment of the system, was made in co-operation with engineering consultants and the Mathematical Advisory Unit (MAU) of the Department.

This study showed that an important advantage is the low noise and vibration associated with the air cushion suspension. A serious disadvantage, as with all air cushion systems, is the power consumed for lift. This is minimized by a novel configuration of the air cushion, but at 12 kW/Mg of weight suspended the power consumed for lifting is comparable to that consumed in propelling the vehicle.

The linear induction motors compare favourably in performance and weight with conventional traction equipment. Advantages of the linear induction motor are its simplicity, the absence of moving parts and the fact that traction does not rely upon any contact with the track. Disadvantages are the low power factor (0·5) and the need for a continuous length of reactor rail at £6000 per km along the track. These disadvantages introduce cost penalties which could be readily assessed for any given URBA application.

1.1.5 Inter-city transport

Studies have been made for the Inter-Departmental Working Party on Inter-City Transport, whose function was to make a comparative assessment of new forms of inter-city transport. Those systems currently being considered are: the Advanced Passenger Train (Plate 8), which will run on existing railway tracks at speeds up to 250 km/h; the Tracked Hovercraft (Plate 9), which will be supported

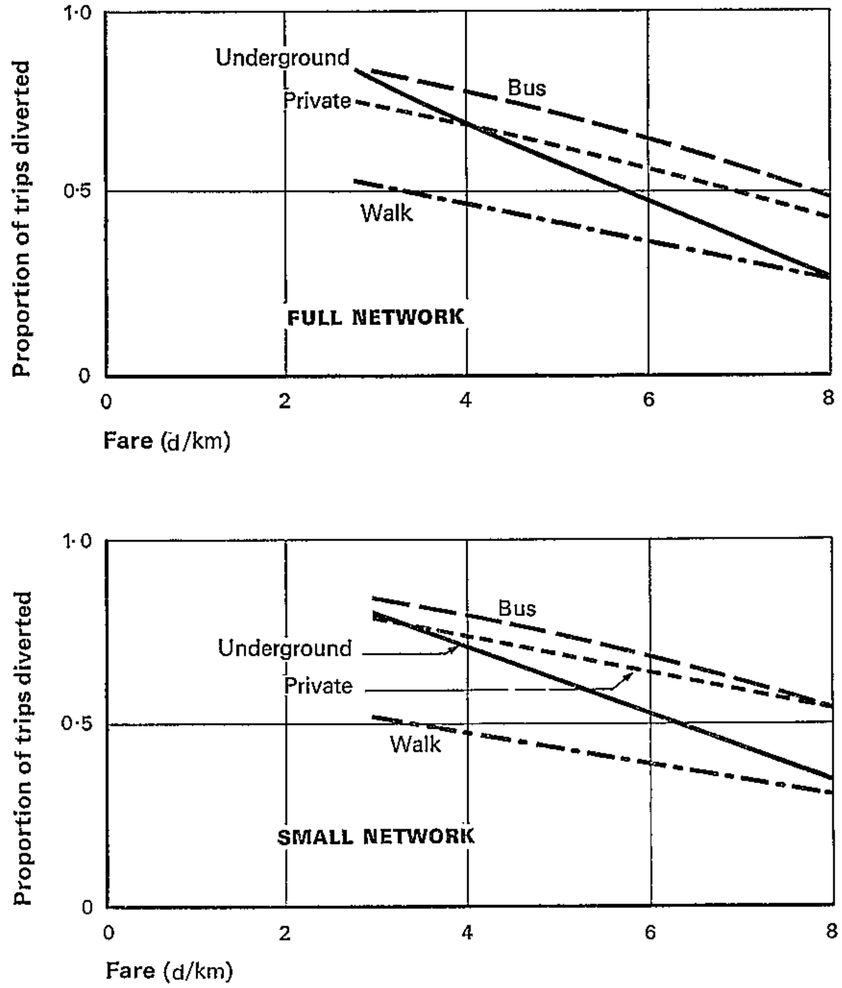


Fig. 12
Proportion of trips diverted to Cabtrack

on air cushions on a concrete track and be propelled by a linear electric motor at speeds up to 400 km/h; and vertical or short take-off and landing aircraft which could operate from small airports in or near city centres, thus reducing the time spent on ground transport to and from airports.

The ultimate objective of the work is to determine what combinations of new and existing forms of inter-city transport might best fulfil national transport requirements in 15 or 20 years time (when radically new systems might be expected to be in regular use). Aspects of new transport systems which must be assessed are their ability to provide adequate and efficient transport at future traffic levels, their development, installation, and operating costs and their possible social and environmental effects.

Two routes, for which some travel survey data are available, were selected for the initial studies. They are London–Manchester and London–Glasgow with lengths (300 km and 650 km) which are fairly typical of inter-city routes in both this country and Europe. The costs of operating each transport system on both routes have been estimated, using, as far as possible, a common basis for comparison. The market shares likely to be attracted by each mode of transport in various competitive situations were estimated using a behavioural model (see *Road Research 1970*,[6] p. 8) and combined with projections of total demand to give numbers of travellers on each system, and hence its overall costs and revenues in future years. Factors other than commercial viability are important in cost benefit analyses and are still being evaluated. They include the value of time saved by improvements in transport, the impact of new transport system on regional development, and problems of noise, pollution and other forms of disturbance.

1.1.6 Flywheel energy storage

As a possible pollution-free, low-maintenance vehicle for use in cities, the battery electric car has attracted considerable attention. An alternative energy storage system of rather less obvious potential is represented by the flywheel. Flywheels have in fact been used for many years, in a secondary role, as power output smoothing devices. In a study in TRAG the flywheel was examined with more emphasis being placed on its use in a primary propulsion system.

A critical parameter of any vehicle primary propulsion system is the energy density, which is defined as the amount of energy which may be stored per unit system mass. A flywheel stores energy as kinetic energy and its energy density is a function of the specific strength of the flywheel, i.e. the ratio of allowable working stress to density. The advent of new high specific strength materials, typified by carbon fibre reinforced plastics, has led to a reconsideration of the potential of flywheel energy storage. Rabenhorst[16] at Johns Hopkins University discusses a projected 'super flywheel' having an energy density of 200 kWh Mg, which is comparable with the advanced technology sodium-sulphur battery. Currently the availability and cost of these advanced technology solutions makes it more realistic to compare a steel flywheel with a lead-acid traction battery, both of which have an energy density around 20 kWh Mg.

With the same severe energy density limitations as current battery electric systems, it seems logical to look for flywheel applications in situations where range, and thence total energy requirements, are minimal; milkfloats, delivery vehicles, and special purpose city cars. With energy at a premium and a duty cycle including frequent stops, regenerative retardation is of prime importance. The problem of providing a minimum loss, reversible coupling between the inflexible, virtually constant speed flywheel and the variable speed output may perhaps best be accomplished using a mechanical continuously variable speed drive or a hydrostatic transmission. Standing energy losses may be minimized by enclosing the flywheel in an evacuated enclosure and by attention to bearing friction losses.

The flywheel primary propulsion system is comparable with a battery electric propulsion system. It may have a limited utility in the transport field. However, its potential can only be fully appreciated by further work aimed at defining in detail a vehicle system for a particular application.

1.1.7 Bus crew scheduling

The interest of TRAG in bus crew scheduling arose from a contract placed in 1968 by the former Ministry of Transport in which consultants examined the possibility of computer scheduling of bus crews at a depot of Manchester City Transport. In 1969 TRAG asked RAE Farnborough to continue the work and develop a working program in collaboration with the Manchester undertaking, by that time a part of South East Lancashire, North East Cheshire, Passenger Transport Executive (SELNEC PTE).

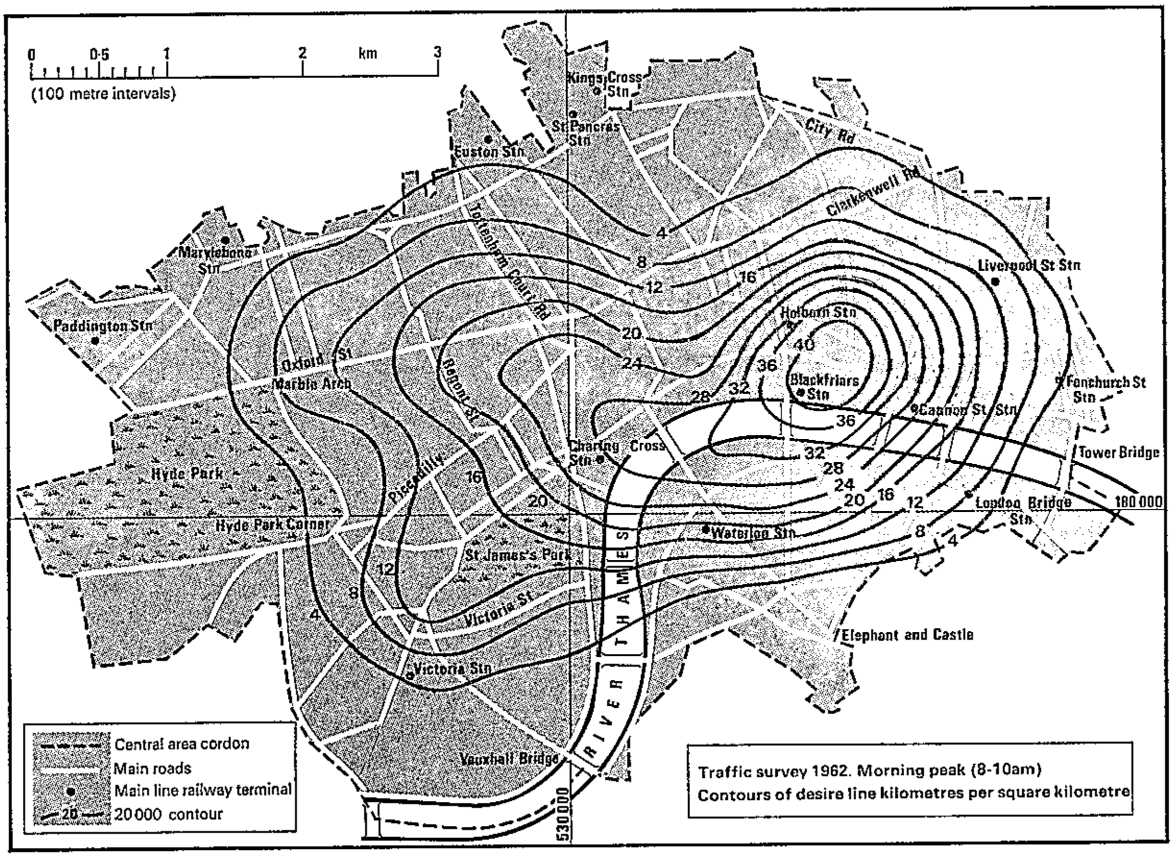
This collaboration has now reached the stage where SELNEC are able to use and modify the program without outside assistance and are currently adapting it to meet new requirements in the SELNEC area. An exercise in which computer produced and manually produced schedules were prepared from the same set of vehicle movements has shown that the efficiencies obtained by the two methods are approximately equal.[17] A survey has been conducted of the crew scheduling practices of a selection of bus undertakings in England and Scotland with a view to assessing what further development is necessary to make the program generally applicable in the bus industry.

1.1.8 Travel demand mapping

The straight lines joining the points of origin and destination of journeys, usually called desire lines, provide a familiar representation of the demand for travel, either observed in the past or predicted for the future. Only a tiny fraction of all the journeys in a town can take place along their desire lines; for the rest, discrete transport routes are established which serve to channel the demand, concentrating travel into a small proportion of the total urban space. Desire lines are supposed to adapt to the available transport routes in a way which reflects the traveller's attempts to minimize costs in relation to benefits. If transport of uniform quality and cost were available everywhere, chosen routes between origin and destination would approximate to those which minimize the distance travelled, and they would not stray very far from their desire lines. If transport services of widely different cost and quality are available, chosen routes may depart some distance from their desire lines in order to make use of superior quality systems.

The density of desire lines within several urban areas has been computed and mapped, with a view to revealing the geographic distribution of travel demand, rather than of journey ends alone. The computing is performed by the program TRIMAP, the digital output of which is input to a general purpose contour plotting programme. An example of a desire line density plot from London Traffic Survey (1961) data is given in Fig. 13.

Fig. 13
Underground trips within Central London



Besides yielding a quickly appreciated picture of the shape and intensity of the travel demand specified by any trip matrix, the topography of the desire line density surface contains information relevant to decisions on the location and capacity of new transport facilities. The technique should therefore assist in the selection of efficient lines and networks for evaluation by current transport planning methods.

1.2 Environment Section

1.2.1 Noise

On-site measurement. Although motorways are potentially the noisiest of our roads, at present the urban motorway mileage is small compared with the mileage of urban trunk roads and through roads and these are at present the major source of urban traffic noise. A survey of environmental noise levels has been made in the vicinity of Queslett Road, a B class road in Birmingham.

The primary purpose of the survey was the provision of information on objective levels to complement a study by Keele University of the economic impact of varying traffic noise. A secondary purpose of the experiment was to test in field conditions the 10 microphone logging set described in *Road Research, 1969,*[5] p. 78, and the computer program to analyse the data.

The primary purpose was met by measuring, over 24 hour periods, noise levels at 42 façades representative of the 400 or so residences included by Keele in the survey. To further the second aim an additional 20 points were measured, principally in back gardens. The data have been sorted and analysed on the Laboratory's computer using a Fortran program developed at the Laboratory and the output results have been mapped using the Calcomp General Purpose Contouring Program (GPCP). Figure 14 shows a segment of the GPCP plot of the L_{10} index.

Experience with the equipment indicates that at reasonable sites in good weather 24 hour data for 10 microphones can be collected and analysed over four days and requires about 70 man hours (mainly in travel, site preparation and clearing). The analysis program is fully operational. The results indicate that to improve the precision of the derived noise indices the current rate of data acquisition, 180 observations per microphone per hour, should be

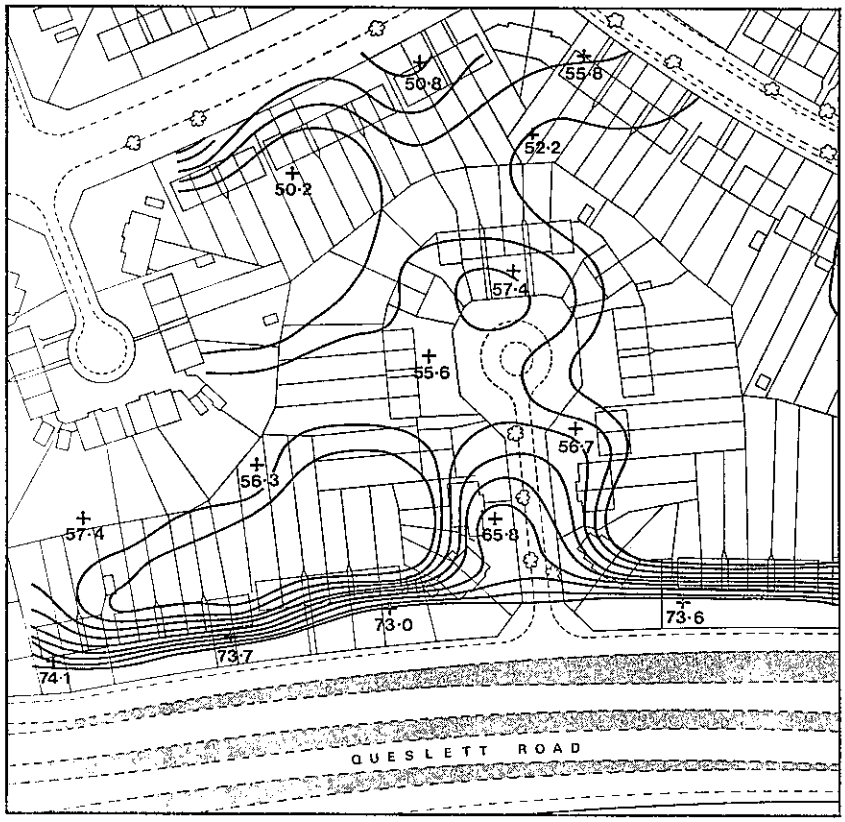


Fig. 14
Computer drawn contours of L_{10} index

increased. This will probably involve changing the data logger from paper tape to magnetic tape recording. The GPCP mapping program is not completely suited to noise mapping since there is no subroutine to cope with the sudden noise field discontinuities that arise at a barrier. This can be seen on Fig. 14 where the L_{10} contour lines cross houses quite smoothly although a house is a very effective barrier and represents a severe field discontinuity. The map even with this limitation does provide an easily assimilated presentation of the variation of noise over the site.

Lorry tyre noise. A preliminary investigation of the effects on noise of tyre tread pattern, tyre material and road surface texture has been made. In these tests various sets of tyres were fitted to an unloaded lorry. The lorry coasted at five speeds in the range 30–100 km/h on three surfaces; smooth concrete (Monolithic granolithic concrete flooring artificially polished), coarse quartzite macadam [$\frac{3}{8}$ inch (10 mm) quartzite carpet to BS1621[18]] and motorway asphalt and precoated chippings to BS594.[19] The noise emitted was measured and recorded at a point 7·5 m from the lorry centre line.

On dry surfaces two highway type tyres were almost as quiet or even quieter on the coarse quartzite as on the smooth concrete. All tyres were noisiest on the motorway asphalt surface. On the wet surfaces patterned tyres tended to be quieter on the coarse quartzite than on the smooth concrete or motorway asphalt surface. On average the noise from the wet surfaces was about 10dBA greater than from the dry surfaces. The difference is mainly in the range 2–5 kHz, this representing the well-recognized hiss from tyres on wet roads. Although these results are very tentative they do indicate that some reduction of rolling noise can be achieved by attention to the road surface specification without necessarily leading to a reduction of skid resistance.

1.2.2 Air pollution group

After reviewing the present state of knowledge of air pollution resulting from vehicle emissions[20] a research group has been set up to collect data in order to identify the extent of the problem in the United Kingdom. Facilities are being set up for the measurement of the major pollutants—smoke, sulphur dioxide, carbon monoxide, particulate lead, hydrocarbons and oxidants (ozone and nitrogen oxides) together with the equipment to record the meteorological conditions.

The research group has already carried out, in collaboration with the Warren Spring Laboratory, a pilot study during June and July 1971 in London Road, Reading (Principal Road A4). The background level of pollution in the area was also measured so that the contribution of vehicle emissions to the general level of air pollution could be identified. The results are being analysed and reports of the work will be issued in due course.

1.2.3 Environmental assessment

Realistic Environment Assessment Laboratory (REAL). In order to overcome some of the problems associated with evaluating changes in environmental conditions a simulator was built to reproduce some of the conditions brought about by traffic variations. Initially it is restricted to changes in visual intrusion and noise levels. The basic idea is to place people in what appears to be an ordinary living room into which are projected traffic scenes and their associated noises. By modifying these effects it is hoped to obtain assessments of the relative values of combinations of environmental factors which could be associated with particular developments.

REAL is a room, 5·5 m × 4·3 m, furnished as a lounge which can seat up to 10 people. On the middle of one wall is a window 1·8 m × 1·2 m. Outside the window about 0·3 m away is a screen on the back of which is projected a moving picture of a scene as viewed from the room. Apart from the 'room', REAL consists of the space required for projecting the film and relaying the noise effects. A major problem in design has been how to achieve a sufficiently bright and realistic view outside whilst retaining an appearance of daylight within the room. This has led to compromises between light levels and the space required for the 'room' and the space required for projecting purposes. The projector is a standard 16 mm model fitted with a special quartz arc lamp which produces near four times the illumination of a standard lamp.

Creating the impression that the viewer is in a room looking at traffic outside raises a number of filming problems. The films have to be taken with a fixed camera which imposes limits on the steadiness of the camera and the projector. Taking actual scenes from houses close to the roadside introduces problems of perspective.

The construction of REAL was completed early in May and a quarter hour film portraying five quite different scenes was produced for showing during the Open Days later that month. For most of the time the film was shown continuously but for four periods each day admittance was by ticket only; after a brief introduction and seeing the film right through the visitors were requested to fill in a short questionnaire. Altogether 177 questionnaires were completed. To the question 'how would you rate this simulation of the environment in a room adjacent to the road?' 31 per cent replied 'very realistic', 65 per cent replied 'realistic' and 4 per cent 'not very realistic'.

Since Open Days, work has concentrated on improving the methods of presenting the views and the noise, and on developing methods of using the simulator and analysing the results. A start has also been made on taking further film.

Environmental effect of a by-pass. To assess some of the environmental effects of building a by-pass to a small country town a 'before and after' survey is being carried out at Alton in Hampshire. The 'before' part of the survey was carried out in July and August 1971 shortly before the by-pass opened, and the 'after' part is planned to take place about the same time of the year in 1972. An opinion survey was carried out amongst residents, shop keepers and office workers in Alton High Street and in two control areas: Alton, away from the High Street and Bentley on the A31 to the North of the by-pass. Noise measurements and traffic counts were made at the same places and an interview survey of pedestrians in Alton High Street was carried out.

1.2.4 Tropical research in the Environment Section

The Environment Section have a mixed team of UK and locally recruited staff operating in East Africa. The work started in 1966, and is concerned with rural and urban flood hydrology, and erosion. Parts of the programme are being undertaken under contract by King's College of the University of London and the National College of Agricultural Engineering in Bedfordshire. Both teams work in close co-operation with the relevant Government departments in East Africa. This work is additional to that carried out by the Tropical Section (see Section 5.5).

Urban storm water sewer design. Results are available illustrating how the RRL method of surface water sewer design can be modified for use in the tropics.[21] For a conventional sewer system on a heavy clay catchment in Nairobi the run-off from unpaved areas was satisfactorily modelled by estimating the run-off volume using a simple run-off coefficient, varying between 0–0·9 depending on antecedent rainfall conditions, and routing this through a linear reservoir with a three-hour lag time. Data for other soils and catchments of differing slope are still being collected to produce design curves for predicting lag times and run-off coefficients for any catchment.

Measurements have also been made on a catchment where run-off from roofs and paved areas is discharged on to grassed areas before entering the drainage system, to establish whether this common practice results in significantly reduced flows in sewers under tropical conditions.

Flood estimation for the design of bridges and culverts. Data collection is proceeding from a network of rural representative catchments in Kenya and Uganda. A non-linear reservoir model is being developed as an alternative to the Unit Hydrograph Method for converting effective storm rainfall into flood run-off.

Road side erosion. The problem of soil erosion from shoulders of new roads has been investigated on typical experimental sections of two roads in Kenya. These trials were aimed mainly at establishing a quick grass cover and comparing methods of protecting the road shoulders until the grass had grown sufficiently to inhibit soil loss effectively.

The unreliability of rainfall in the semi-arid areas of Kenya is a problem in such work. A further series of tests using rainfall simulators and intended to cover the steeper slopes of high embankments and cuttings is being planned under a research contract with the National College of Agricultural Engineering, Silsoe, Bedfordshire.

The object of this programme is to extend the use of the 'Universal Soil Loss Equation', developed by the US Department of Agriculture, to East African soils, to the steep slopes found on highway reserves and to allow for the additional erosion caused by surface run-off from the road pavement on to shoulders and embankment slopes.

1.3 Urban Transport Planning Section

1.3.1 The CRISTAL Urban Transport Model

Reference was made in *Road Research 1970*,[6] p. 36, to a strategic urban transport planning model known as CRISTAL. A paper[22] giving more details has been published during the year. The object of the model is to enable rapid comparisons to be made of the economic benefits of alternative transport investment and pricing strategies in large urban areas. Development of the set of computer programs has continued and production of useful results has started. As a first application, the model has been set up to study an example network with characteristics similar to those of Greater London.

Most of the data required to calibrate the model were obtainable from published sources, though new surveys of travel times were necessary (see Section 1.3.2.). While most of the data could be entered directly into the computer model, the parameters concerned with the numbers of trips had to be adjusted until the model reproduced sufficiently well, the observed numbers of trips from each area to each other area by each mode in the required ring-radial symmetrical form.

The initial calibration of the model related to demand levels and traffic conditions in 1970. A proposal for some future year can be assessed relative to alternative proposals, which may include a situation with no new transport system features. The model is run for each proposal separately. Growth factors represent changes in demand, and transport networks are modified to represent the transport investment or policy being evaluated. Each evaluation requires two computer runs, each taking about one hour, representing peak and off-peak conditions. Each run operates without a break, the various modules representing trip generation, assignment and other factors being called in by a master programme.

Present indications are that the iterations converge after five cycles and that the results obtained are plausible. A programme of applications of the model has been planned. This includes a series of tests of alternative motorway networks, various pricing policies for both private and public transport, and alternative public transport systems. Sensitivity tests are being carried out to check the reliability of the conclusions.

Figures 15, 16, and 17 illustrate some of the results of early applications of the model. They show how the amounts of travel and the benefits vary as the assumed motorway network is, at increased total cost, extended towards the centre by successively adding more ring and radial sections. Figure 15 indicates that, on average, existing roads would be relieved by building larger amounts of motorway, despite an increase in total road travel. Figure 16 suggests that rail usage would diminish somewhat with increasing motorway investment. Figure 17 shows that benefits, as a proportion of costs, are less for motorways close to the centre than for those further out. In these diagrams the 'no new system' situation, represented by the vertical axis, does include an orbital road and the most extensive systems include motorways extending to the centre of the network.

1.3.2 Journey time surveys

Surveys of journey times,[23, 24] by car, bus, and rail were carried out between March and June, 1970 for similar trips to those made by car or

Fig. 15
Amount of road travel on CRISTAL example network in relation to the extent of the motorway system

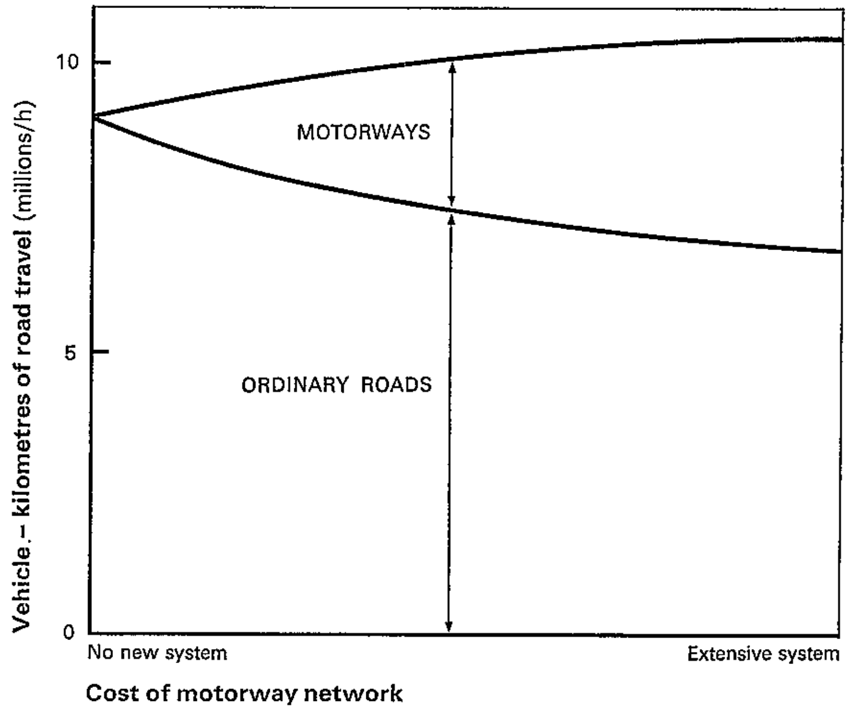


Fig. 16
Passenger travel on CRISTAL example network in relation to the extent of the motorway system

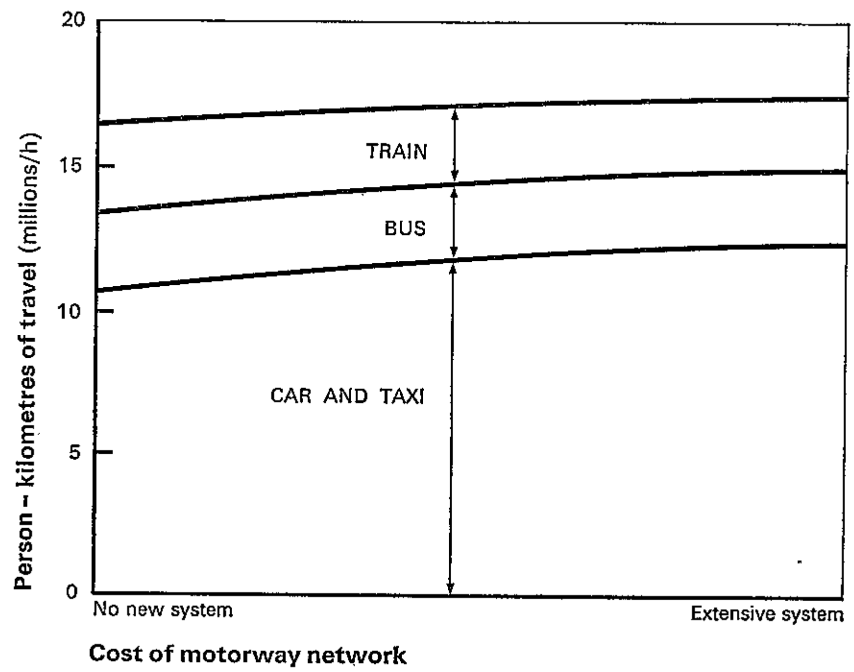
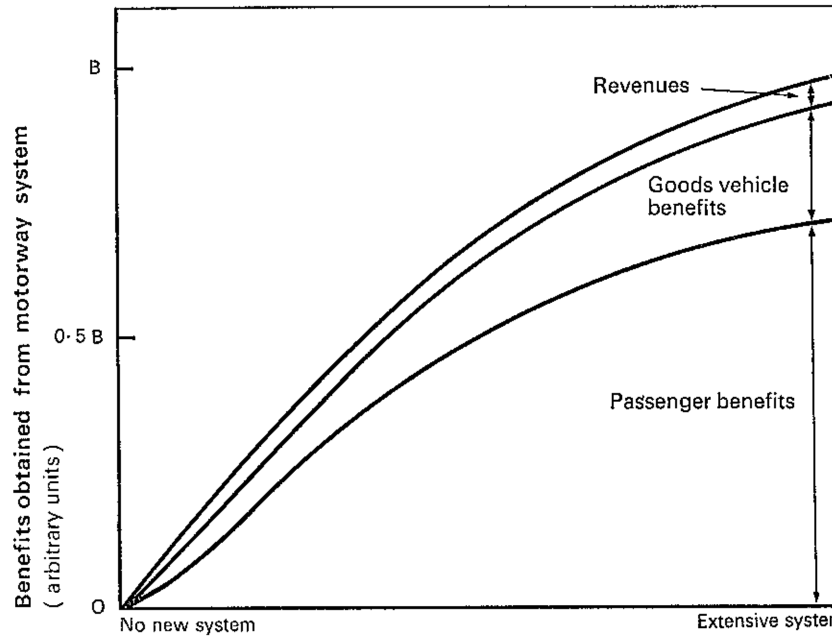


Fig. 17
Benefits of increasing the extent of the motorway system on CRISTAL network



public transport for the 1962 London Traffic Survey. Walking, waiting and on-vehicle times were identified separately for the public transport trips. The data were analysed to show how the journey times varied between ring and radial routes and by distance from the centre (see Tables 4 and 5).

The results were used to derive journey times for radial and ring links of the CRISTAL networks in such a way that the point to point journey times on the model network reproduced as closely as possible the actual point to point times on the real road and rail networks.

Table 4: Average car speeds by distance from centre

Distance from centre (km)	Central 3·2 km	8	16	24	32
Ring route speeds (km/h)					
Offpeak	20	31	41	48	52
Peak	19	25	37	46	52
Radial route speeds (km/h)					
Offpeak	21	26	48	55	60
Peak: high flow direction	19	25	38	60	66
Peak: low flow direction	21	30	44	50	53

1.3.3 The time stability of transportation planning models (Reading survey)

An investigation has begun into the stability over about 10 years of some of the models and parameters used in transportation planning based upon a repeat survey of travel in the Reading area.

A 1962 survey was initiated by Dr M. A. Taylor, for RRL,[25] to provide data for three similar medium-sized towns; Gloucester, Northampton, and Reading.

A repeat survey has been completed in 1971 to produce data compatible with that obtained for Reading in 1962. The Local Government Operational Research Unit was appointed as Consultants to plan and to undertake the fieldwork. The techniques used for collecting travel information included household and roadside interviews on a sample basis, measurement of volume and composition of traffic on certain roads in Reading and at the boundary of the survey area and postcard questionnaires for bus and rail passengers. RRL provided automatic traffic counters and measured journey times by car.

The primary objective of the analysis at RRL is to examine the stability of traffic models, particularly at the trip generation and distribution stages, by comparing 1962 and 1971 models, and testing the ability of each to represent travel at both dates. The availability of income data allows travel cost/income relationships to be studied. More flexible geocoding of addresses will be tried to enable comparisons with the results of the 1971 National Population Census.

Table 5: Average public transport terminal times (minutes)

	Bus			British Rail			Underground		
	Initial walk	Final walk	Initial Wait	Initial Walk	Final Walk	Initial Wait	Initial Walk	Final Walk	Initial Wait
Offpeak	4	4	6	7	8	14	7	6	5
Morning peak	6	3	4	9	9	3	9	5	3
Evening peak	2	5	6	8	6	5	5	6	2

1.3.4 Novel techniques for traffic assignment models

The Road Research Laboratory Transport Analysis Program (RRLTAP)[26] suite of transportation planning programs was designed both for modelling transport networks and for research into techniques. In order to study pricing strategies for the restraint of traffic by fiscal means, it is necessary to use a simulation technique that can reproduce patterns of traffic flow over a congested network with a high degree of consistency and hence provide a means to:

1. Assess the quality of a simulation of congested flow.
2. Improve a simulation of congested flow of inadequate quality.
3. Compare the economic effects of two different fiscal (or other) strategies with confidence in the significance of the comparison.

As the prime objective is to compare the economic benefits resulting from the response of travellers to specific policies affecting them, consumers surplus is of direct value as a criterion[27] for both stability and precision of a flow assignment.

The process of balancing the desire of travellers to use routes of minimum cost against the flow/speed characteristics of the roads that they can use requires an iterative process of determination of current minimum cost routes and consequent reallocations of traffic to different routes. If at any stage this process is halted, the current costs and flows may be taken to define a basic situation and any subsequent iterations will produce a new set of costs and flows which give rise to a consumers surplus (or loss) when referred to the arbitrary 'basic' state.

The internal consistency of the current flow pattern can then be assessed by computing the consumers surplus that arises when the speed of travel on each road is forced to the value defined by its speed flow relationship that corresponds with the total flow then assigned to it. The 'benefit' change thus produced is a measure of the precision to which overall benefit calculations based on this simulation can reasonably be taken. This, however, sheds no light on systematic errors inherent in the flow simulation, and a process of refinement is necessary to reduce system interactions and estimate the residual errors.

If the total number of trips between two points on the network is defined to be a function of the minimum cost of such a trip, the base point for a hypothetical consumers 'surplus' calculation also provides a set of calibration values for such a function. If an arbitrary set of prices is applied to the network, the travel demand function for each origin/destination pair in turn determines the change in number of trips. This is a self-adjusting process, and for a good flow simulation the change in the number of trips at each iteration will have automatically dropped to zero. If the set of arbitrary prices are then removed, the model returns towards a simulation of the initial state. The total numbers of trips are adjusted to the original figures and a consumers 'surplus' calculation will then give zero change if the initial flow simulation was already of high quality. Figure 18 shows the behaviour of the 'surplus' through several stages of this perturbation process. Such null measurement techniques can be extremely powerful, and an indication of their effectiveness in this application is shown in Fig. 19 where a particular strategy was simulated on the basis of unrefined (index 1), partially refined (index 2), and fully refined (index 4) simulation of the initial situation. The net benefit in this case is the difference between toll revenue and consumers loss, and Fig. 19 shows how this changed from a false value of zero for the unrefined initial simulation to a considerable positive benefit for the fully refined simulation.

This null technique can be used as a highly convergent congested assignment procedure.

Fig. 18
Perturbation benefits for three rounds of flow assignment refinement

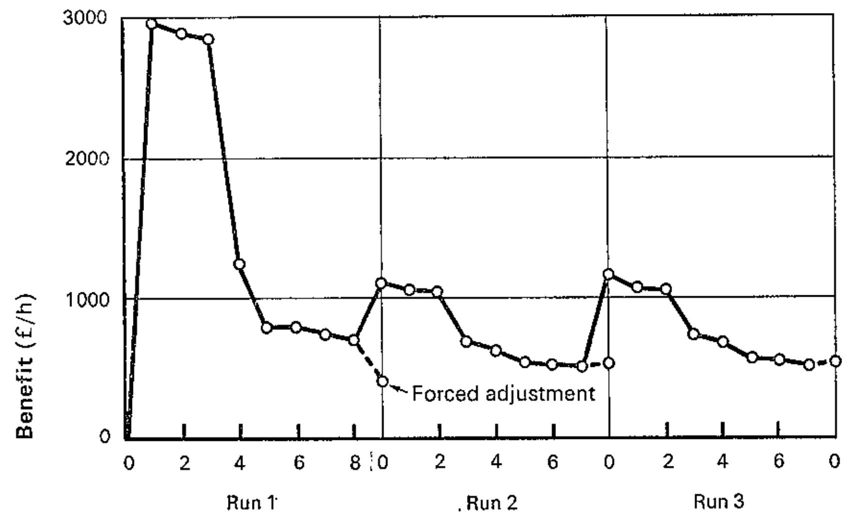
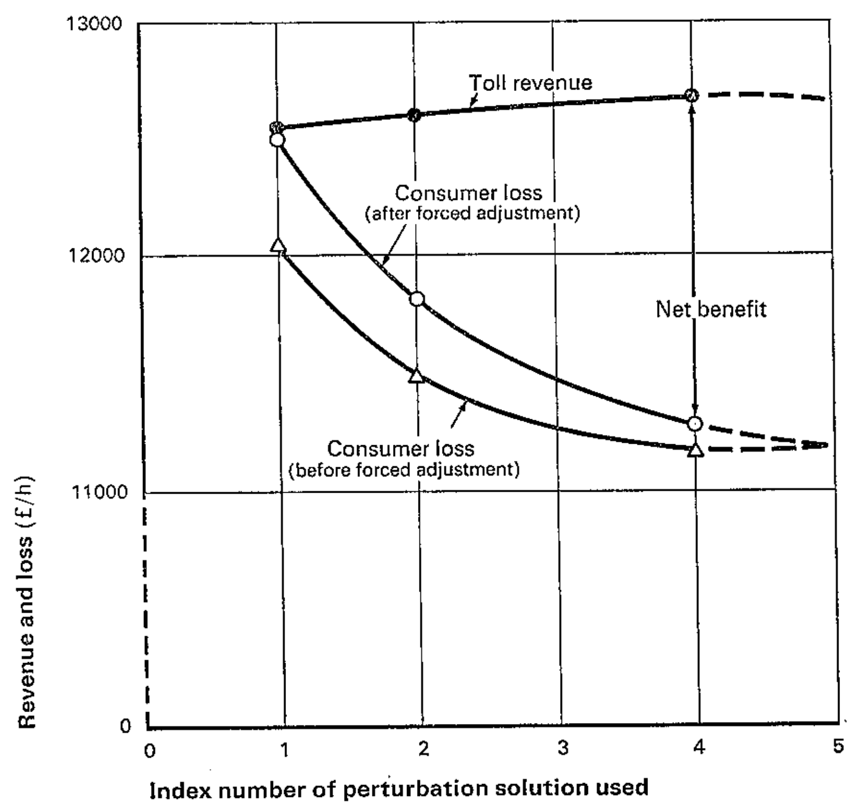


Fig. 19
Revenue and loss results for marginal social costing based on different stages of the improvement of the initial simulation



The techniques now form a standard component of all RRLTAP congested network studies and can be adapted by users of other transport planning suites without modification of the programs themselves.[28]

The internal consistency and precision that can now be achieved on RRLTAP is sufficient for us to be able to optimize particular sets of parking and pricing charges by small stages with full knowledge that the systematic and other internal errors have been reduced as far as possible and are of known magnitude. Without this knowledge, the current studies of traffic management and restraint policies[29] on congested networks could not have been undertaken.

1.3.5 Forecasts of vehicle ownership and use

Forecasts of the numbers of vehicles and amounts of traffic in Great Britain were presented in *Road Research 1970*,[6] p. 39. The data for commercial vehicles were based on trends in such factors as megagramme-kilometres, gross domestic product and average carrying capacity of the vehicles.

Data from a survey of road goods transport conducted in 1967–68 by the Ministry of Transport have since become available and it was found that the recent rate of growth of megagramme-kilometres by goods vehicles has previously been underestimated. The forecasts of medium and heavy goods vehicles have therefore been revised, as shown in *Table 6*.

Table 6: Forecasts of numbers of and travel by medium and heavy goods vehicles in Great Britain

Year	No. of vehicles ($\times 10^6$)	Vehicle kilometres ($\times 10^9$)
1970*	0·6	19
1980	0·7	21
1990	0·8	24
2000	0·9	28
2010	1·1	33

*Actual figures.

1.3.6 Economic factors of traffic generation

Data on expenditure on travel from the annual *Family Expenditure Surveys*[30] were used to estimate the amounts of travel per person by the different modes for household at various income levels. Relations between expenditure on travel and income, and between amounts of travel and income, are shown in Figs. 20, 21 and 22 averaged over the period 1959–68.

Further work is in progress on the estimation of the effects of income, price and cross elasticities of demand for travel by different modes.

Fig. 20
Relations between expenditure on travel as percentage of total expenditure and income per person per week (1963 prices)

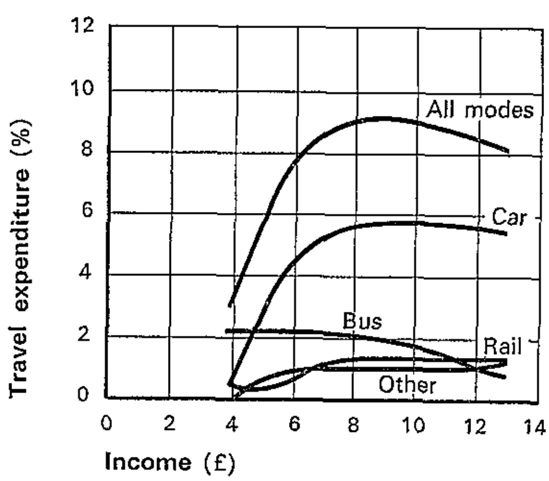


Fig. 21
Relations between inland passenger kilometres per person per week and income per person per week (1963 prices)

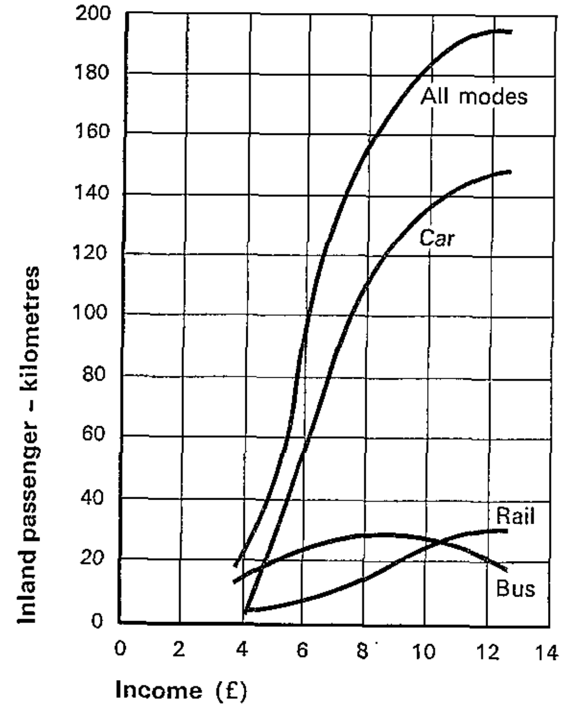
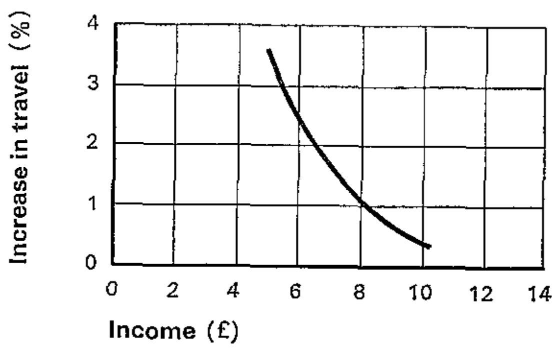


Fig. 22
Percentage increase in travel for 1 % increase in income at various levels of income per person per week (1963 prices)



2. TRAFFIC DIVISION

2.1 Public Transport Section

2.1.1 Bus and car travel in towns

Road Research 1969,[5] pp. 29, 30, reported the results of theoretical studies into the effect of varying the size of bus in the central London fleet on travel speeds and on the overall costs of travel (time plus operating costs), for different levels of private car restraint. The studies indicated that a 40–50 seater bus was the optimum and that with total restraint of private traffic the overall costs of travel (1966 figures) would be reduced by about 17 per cent (a saving of about £18 million per annum for central London). These calculations ignored the 'costs', borne by drivers who transfer to bus travel, in loss of comfort, convenience and privacy which the private car provides. Later work has attempted to evaluate these 'costs' by assuming that if a progressively increasing charge were levied on car travellers, one by one they would transfer to bus travel and that at any particular level of charge, r, the total costs of those transferring must be equal by both modes, i.e. 'comfort' costs + bus costs (fares + time costs) = r + car costs (running costs + parking + time costs). In order to estimate what proportion of drivers transfer on each level of charge the concept of a cross-elasticity of demand between car and bus travel is introduced and its value is assumed to be unity, i.e. if the ratio of the costs of car and bus travel doubles, the ratio of car to bus usage halves. Thus, the number of car drivers transferring to bus travel at any particular level of charge can be obtained using this rule, and, from the above equation the 'comfort' costs can be estimated. By varying this hypothetical road pricing charge, a distribution of 'comfort' costs can be obtained. If these costs are added to the time and operating costs it is found that the 'optimum' travel situation (i.e. minimum overall travel costs) arises when roughly 45 per cent of the present car users transfer to bus travel. Whereas, without these costs included, full restraint gave the lowest overall costs; with them included full restraint gives the highest costs. At the optimum level of restraint the overall travel costs (updated to 1968 figures) would be expected to fall by about 6 per cent and this would amount to a saving for central London of about £7 million per annum; at this level of restraint also, the bus size which minimizes overall costs is found to be a 40 seater. Overall speeds (in a straight line between origin and destination) of all travellers during peak periods would be expected to increase with increasing restraint from about 6 km/h at present (1968) to 8 km/h at optimum restraint and to a little over 8 km/h under full restraint. Present bus passengers' speed would increase from 5·5 km/h to 8 km/h whereas car travellers who changed to bus travel would experience virtually no change in journey speed at the higher levels of car restraint. Of course, those who remain with their cars could enjoy speeds of up to about 22 km/h at almost full restraint.

A further modification to the model introduced separate elasticities of demand for travel for all types of vehicles—buses, cars, goods vehicles, and taxis, so that the model was no longer dependent on the assumption of a constant amount of car and bus travel in total or constant flows of taxis and goods vehicles. This made no change to the optimum bus size but did suggest that the optimum degree of private car restraint was less than the fixed-demand model had suggested. This model, with elasticities of demand for travel of all types of vehicles of unity indicates that about 30 per cent of peak car traffic should be restricted. The net benefit for central London with this degree of restraint was estimated at about £15 per km/h (£8·5 million per annum).

The model has been used with traffic data from Bristol and Reading and for these towns a 40-seater bus yielded the maximum benefit. The optimum degree of restraint in these two towns was 30 per cent of present car flows. The net benefit brought about by restraint is estimated to be £11 per km/h and £5 per km/h respectively assuming again that elasticities of demand for travel are unity. Sensitivity tests indicated that the overall benefits in all these studies varied from a quarter below to a quarter above the figures given above, as the elasticity coefficient varies between 0·5 and 1·5.

2.1.2 Time spent by buses at stops

As part of its investigation into bus travel in urban areas, the Laboratory has been taking observations on the time spent by buses at stops, picking up and setting down passengers. In an urban area, a two-man-operated bus spends typically 12 per cent of its journey time at stops and this amounts to about two minutes for an average passenger journey. The community losses incurred whilst a bus is at a stop can be listed as follows:

1. Time lost by passengers already on the bus as they wait for other passengers to board and alight.
2. Time lost by all road users due to increased traffic congestion.
3. Increased costs incurred by the bus company. The lower the bus running speed, the more vehicles will have to be operated to maintain the same level of service.

To gain some impression of the costs involved, it has been calculated that an increase of just one second in the average time that each bus spends at a stop would cost the community about £0·5 million per annum in Central London alone. A variety of urban one-man-operated and two-man-operated bus types has been investigated, with particular emphasis on one-man services. These have included schemes where passengers pay the driver on boarding, partly automated schemes where passengers have the alternative of paying the driver or a machine, and fully automated schemes where all passengers pay machines and driver participation is limited to giving change. The investigations have also attempted to assess the benefits of policies aimed at reducing stopped times, such as simplifying the fares structure and requiring passengers to have the exact fare.

For a one-doorway bus, where boarding takes place after alighting is completed, the stopped time T, can be related to the number of passengers boarding, N, and the number of passengers alighting, F, by the linear expression:

$$T = A + BN + CF$$

where A is a constant called the 'dead time' and B and C are the boarding and alighting time per passenger respectively. For a conventional open rear platform two-man-operated bus, A is about one second and B and C lie between 1 and 1·5 seconds per passenger. With a two-doorway bus, boarding and alighting take place at the same time; the stopped time is determined by whichever is the larger. They must therefore be considered separately and Fig. 23 shows the results for a typical one-man-operated two-doorway bus. Calculations have shown that, for a typical urban route, the average stopped time varies from 8 seconds for a conventional two-man-operated bus to 11 to 21 seconds for one-man-operated buses currently in use in busy urban areas. Such large differences in stopped time with their high associated community costs emphasize the need for careful selection of any one-man operated bus for urban service.

2.1.3 Bus demonstration projects

Two of the Department's Bus Demonstration Projects (see *Road Research 1970*,[6] p. 30) and (*Report to the Minister*)[31] which the Laboratory is assessing have now been implemented, 'before' and 'after' studies carried out and interim reports written.

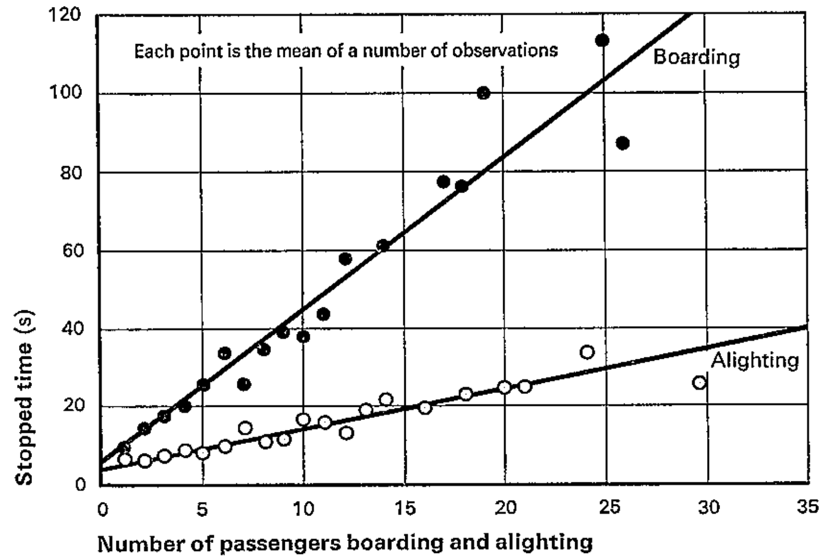
One of these projects relates to the one-way system and contra-flow bus lane introduced in March 1971 in the centre of Manchester. Bus journey time and its variability were both reduced for all those buses now using the one-way system. Car journey time and its variability were also reduced for cars using the main south–north route via the one-way system, though there was a significant disadvantage to cars using other routes through the centre. So far as buses using the contra-flow bus lane are concerned, not all have had their journey times reduced, probably because all buses using the bus lane have to cross the main stream of traffic at both ends of it and the signals at these points introduce considerable delays. Nevertheless, bearing in mind the large numbers of people alighting at stops on the bus lane, there may be a good case for retaining it. The analysis of results is not yet complete but from the interim results it appears that this project may not be a very good example from which to try to draw general conclusions about the utility of bus lanes, due to the many special features of the scheme.

The second project is at Formby, near Liverpool, where a bus-rail feeder service was introduced in November 1970 following the pre-service feasibility study and first report by Hovell and Jones[32] of the University of Liverpool (see *Road Research 1970*,[6] p. 30).

At the end of the first six months of operation a further survey was commissioned by the Laboratory and carried out by the same group to determine the previous modes of travel of those now using the service, their degree of satisfaction with it, their origins and destinations and their regularity of usage. A special effort was made to re-contact those who had expressed an intention of using the service, during the preliminary survey, to establish whether they had, in fact, done so.

The results of the second survey[33] show that the actual demand during the first six months

Fig. 23
Boarding and alighting times for a typical two-doorway, one-man operated bus



of 1971 was about 80 per cent of that predicted and still rising slowly. Demand is thought to have been adversely affected by substantial bus and rail fare increases immediately before and shortly after the service was introduced. Conversions from the private car to the bus-rail mode were disappointing and considerably lower than predicted but this was to some extent compensated by an unexpectedly high demand from new residents in the area and from others who had previously walked to the station. Although the net financial gain to public transport resulting from introducing the service has been appreciably lower than forecast it is still positive and will, it is hoped, increase in the future, especially if current plans materialize to introduce a City Circular Service meeting trains at Liverpool Exchange Station. Responsibility for all bus operations in the area will be transferred from the National Bus Company to the Merseyside PTE early in 1972 and in view of the Authority's expressed desire to continue the service, at least for a further trial period, sponsorship of the project by DOE is being extended until mid-1972.

2.2 Traffic Management and Control Section

2.2.1 Area traffic control

Glasgow. Four comparisons of traffic signal control schemes were made in Glasgow during 1971 using average journey times as the main criterion. Runs with instrumented cars were used to measure journey times on the network; flow counts were obtained via the control computer from the pneumatic detectors at the traffic signals.

SIGOP. Two of the tests compared TRANSYT (see *Road Research 1967*,[34] p. 53), with SIGOP, an alternative method of optimizing fixed-time signal settings which has been developed by the Traffic Research Corporation under contract to the United States Federal Highway Administration.

In one test the same cycle times and green splits were used for both the SIGOP and TRANSYT calculations, so that the co-ordination produced by the two methods could be compared directly.

In the second test the SIGOP settings were compared with double-cycle TRANSYT settings, i.e. settings in which major junctions had the same cycle time as in SIGOP but minor junctions ran through two cycles in that time. The double cycle technique is valuable for networks like Glasgow where multiphase intersections, which require a long cycle time, and simple two-phase intersections have to be co-ordinated. SIGOP is, at present, limited to a common cycle throughout the network.

The results of the two tests are given in Figs. 24 and 25. They show that SIGOP and TRANSYT were equally good when the same cycle times and green splits are used. This is significant in networks where the absence of multiphase intersections enables a short cycle to be used throughout. Double-cycle TRANSYT settings gave journey times of about 5 per cent shorter than those with SIGOP during the evening peak and off-peak periods; there was no measurable difference in the morning peak. With the exception of the morning peak result with double-cycle TRANSYT, the results are in substantial agreement with predictions

Fig. 24
Comparison of SIGOP and single-cycle TRANSYT

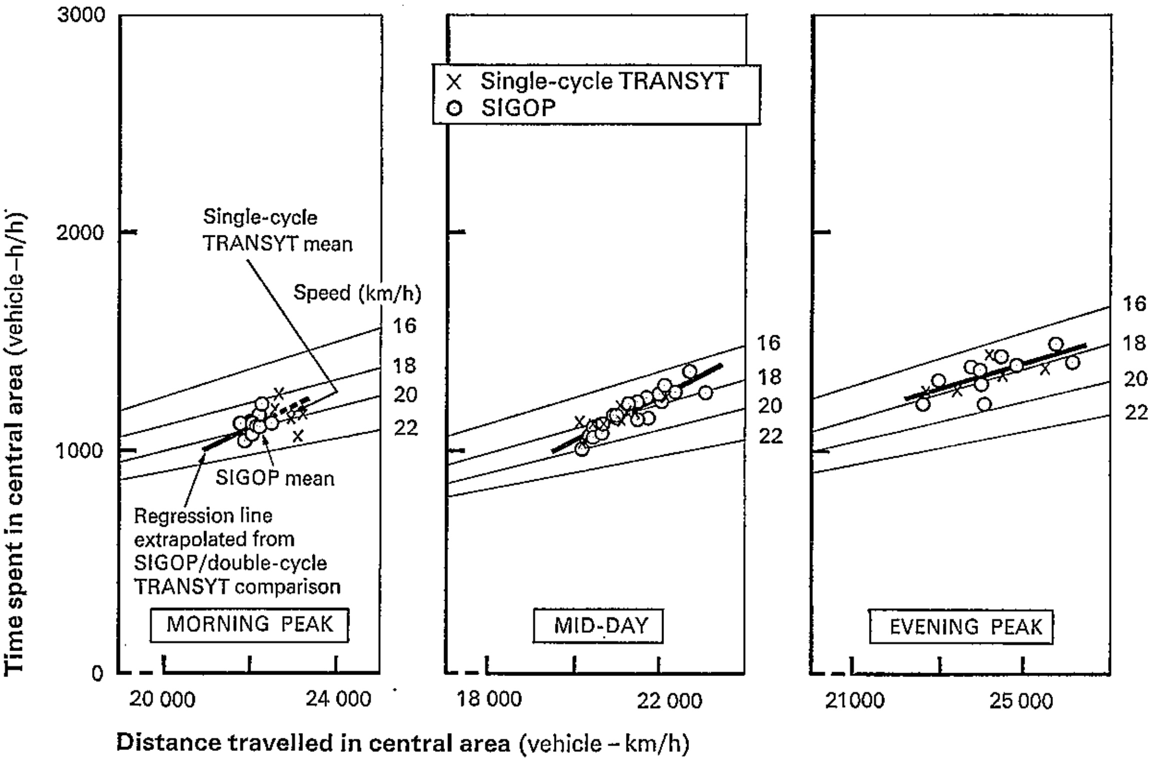
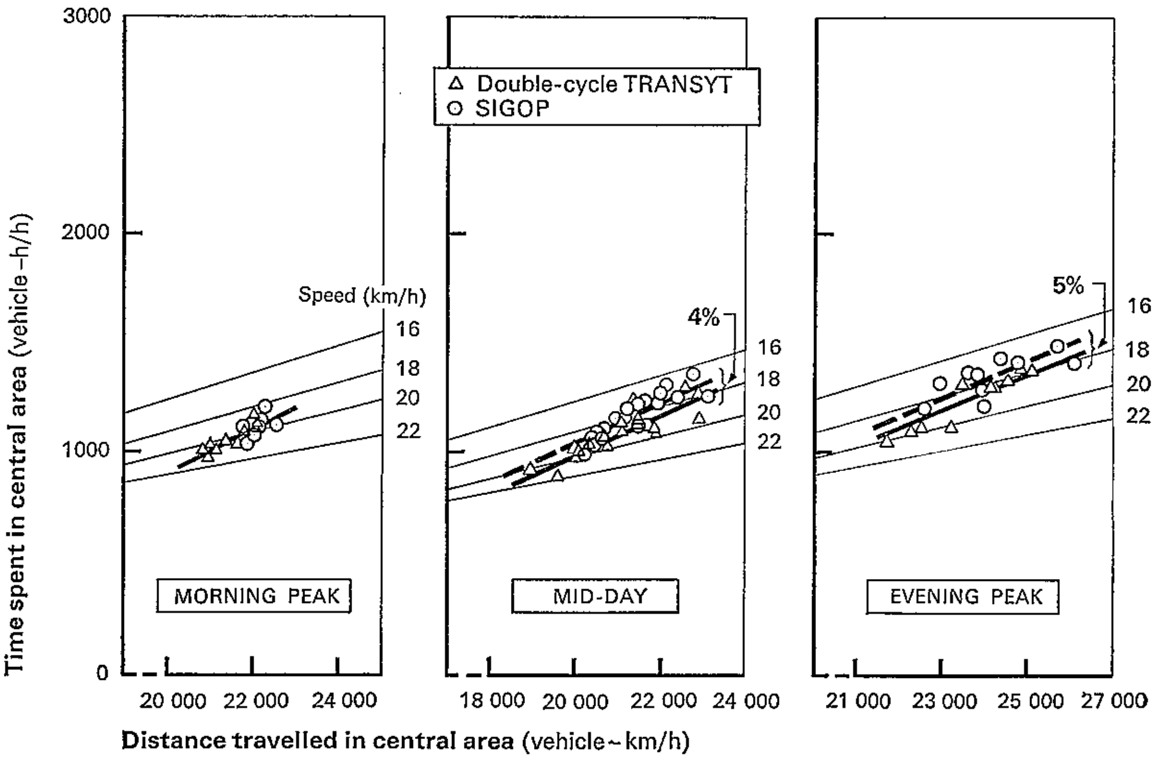


Fig. 25
Comparison of SIGOP and double-cycle TRANSYT



obtained by simulation with the traffic model used by TRANSYT.

Low-flow conditions. The other two tests made during 1971 assessed the merits of co-ordinated fixed-time signals during the evening and in the early morning when flows are much lower than during the day. All previous assessments in Glasgow have been confined to the working day. In the evening test, between 1930 hours and 2130 hours, the normal midday fixed-time TRANSYT settings were compared with a vehicle actuated flexible progressive system having the same basic plan. In the early morning test between 0100 hours and 0300 hours, fixed-time TRANSYT settings, calculated for this time of night, were compared with isolated vehicle-actuation over the whole network.

In these particular tests, the normal signal controllers were used to provide all the vehicle actuated settings; because of this the evening test only covered the central part of the network which is linked by a master controller.

The results are shown in Figs. 26 and 27. Figure 26 shows that with the vehicle actuated flexible progressive system, journey times were about 13 per cent longer than with the same basic fixed-time settings. Figure 27 shows that with very light traffic flow in the early morning, isolated vehicle actuation and fixed-time TRANSYT settings gave similar results.

Overall, the tests have shown that, over the whole range of flow conditions in Glasgow, optimized fixed-time systems of traffic signal control give journey times at least as short or shorter than of the vehicle responsive systems tested.

Dynamic signal plan generation. An experiment to compare two fundamentally different methods of co-ordinating traffic signals in an area was carried out co-operatively by the Secciόn de Circulaciόn y Transportes of the Ayuntamiento de Madrid, GEC Elliott Traffic Automation and the Road Research Laboratory in autumn 1970.

The signals in the centre of Madrid are controlled according to a dynamic signal plan generation system which was the first of the type in the world. This was compared, in Madrid, with a system similar to the most successful fixed-time scheme that had been tried in Glasgow.

Details of the signal-controlled area in Madrid have been given by Valdes and De la Rica.[35] The system in 1970 had 85 traffic signals, divided into eight groups, each group being located by a sub-master controller as described by Fuehrer.[36] Information from 21 detector stations, comprising 76 detectors in all, is collected by a central computer. The dynamic signal plan generation system uses this information to calculate, on-line, the cycle time, splits and offsets to be used at each signal. These calculations can be carried out at times corresponding to any multiple of cycle times; the system in operation during the survey worked on a three cycle basis. The flow counts from the detectors are used to produce smoothed estimates of flow and estimates of saturation flow at each arm of the intersections. Cycle times and splits are calculated from these values to give 10 to 15 per cent reserve capacity on each approach arm. Offsets are calculated to minimize delay to traffic on each link (or where considered necessary to reduce stops) using speeds estimated from speed detectors, or preset speed values, and a simple model of traffic behaviour down the link. When the cycle time and all splits and offsets have been calculated by the central computer the settings are sent to the submaster controller. Any changes are then carried out automatically by the submaster.

The fixed-time schemes used as a comparison consisted of three fixed-time optimized plans, based on historical knowledge of traffic conditions, and selected by time of day. Information on traffic movements at the signalized intersections was obtained from a traffic survey carried out by the Ayuntamiento de Madrid. Pre-set splits were used, and the optimization of the signal co-ordination for each plan was carried out using a 'hill-climb' method similar to the one designed by Robertson.[37]

The comparison was carried out using the same assessment techniques as in Glasgow. Results of the test for three periods of the day are shown in Fig. 28. These show that the dynamic signal plan generation gave longer journey times by about 9 per cent than the optimized fixed-time system.

The data for the evening peak, 1900 hours to 2100 hours, were difficult to interpret, largely because sections of the network were quite frequently blocked by traffic queuing back from intersections outside the computer controlled area. This meant that a substantial proportion of the data had to be rejected. Figure 29 shows comparisons of the two systems after using two different criteria for

Fig. 26
Assessment results for evening survey

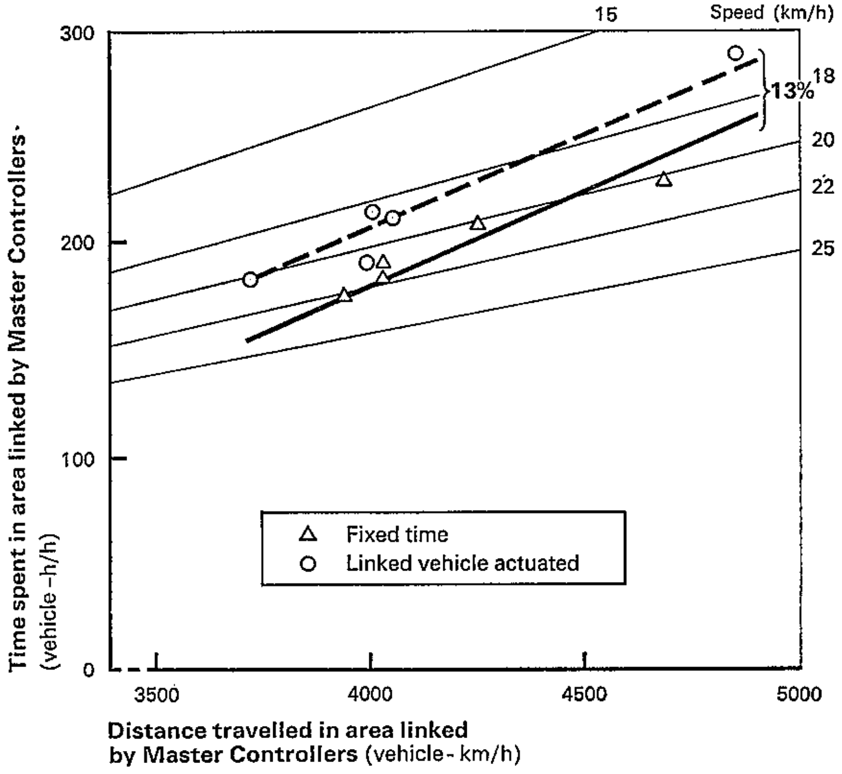
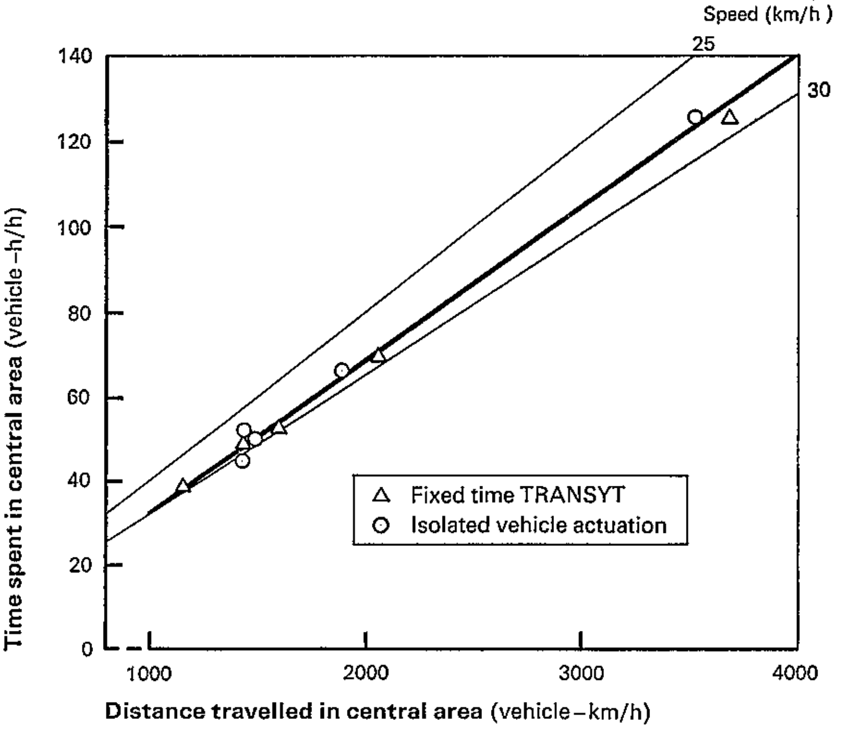


Fig. 27
Assessment results for early morning survey



rejecting data; it indicates that the difference between the two systems during the evening peak was of the same order as during the rest of the day.

A number of improvements have since been made to the dynamic system in use in Madrid. Further research is being carried out by the Ayuntamiento de Madrid, and also by GEC Elliott Traffic Automation Ltd., in association with the Laboratory on various aspects of dynamic signal plan generation.

2.2.2 Motorway traffic characteristics
Some preliminary studies of peak hour traffic characteristics have been made on the east-bound section of M4 between Parkway and

Fig. 28
Study of a dynamic signal plan generation system, excluding evening peak

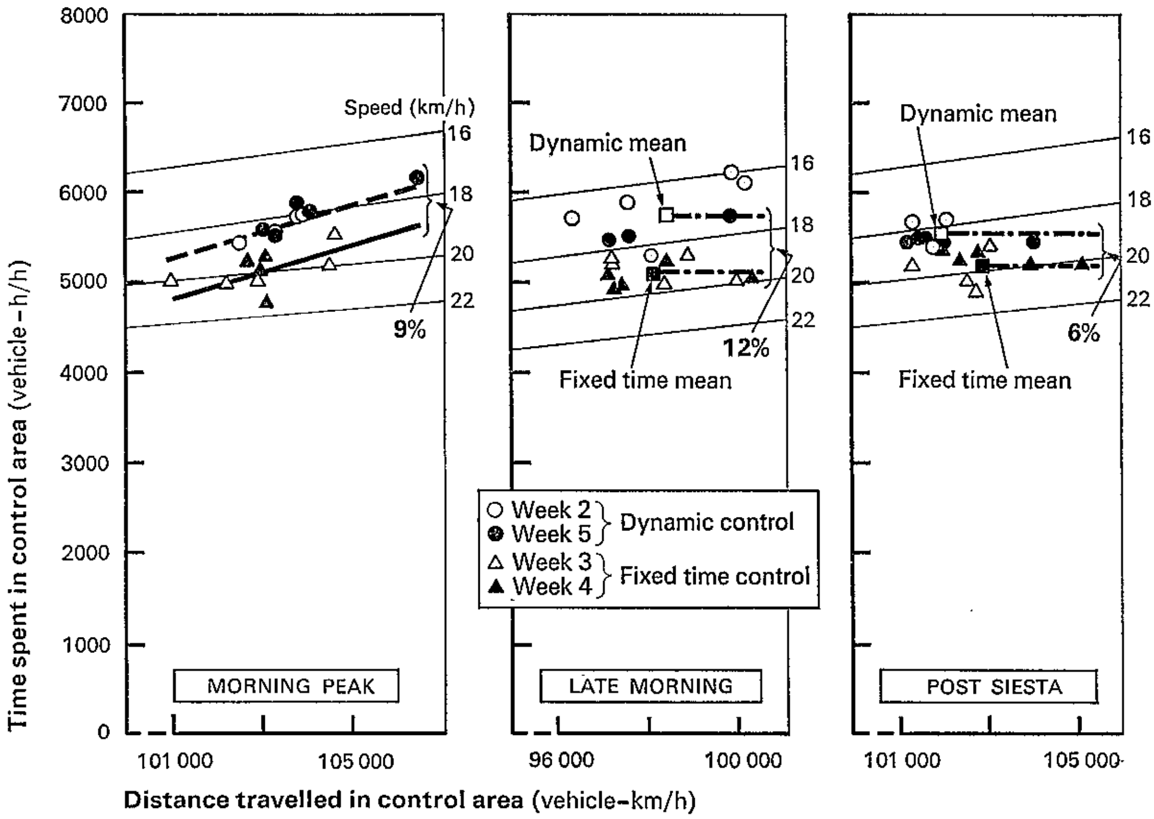
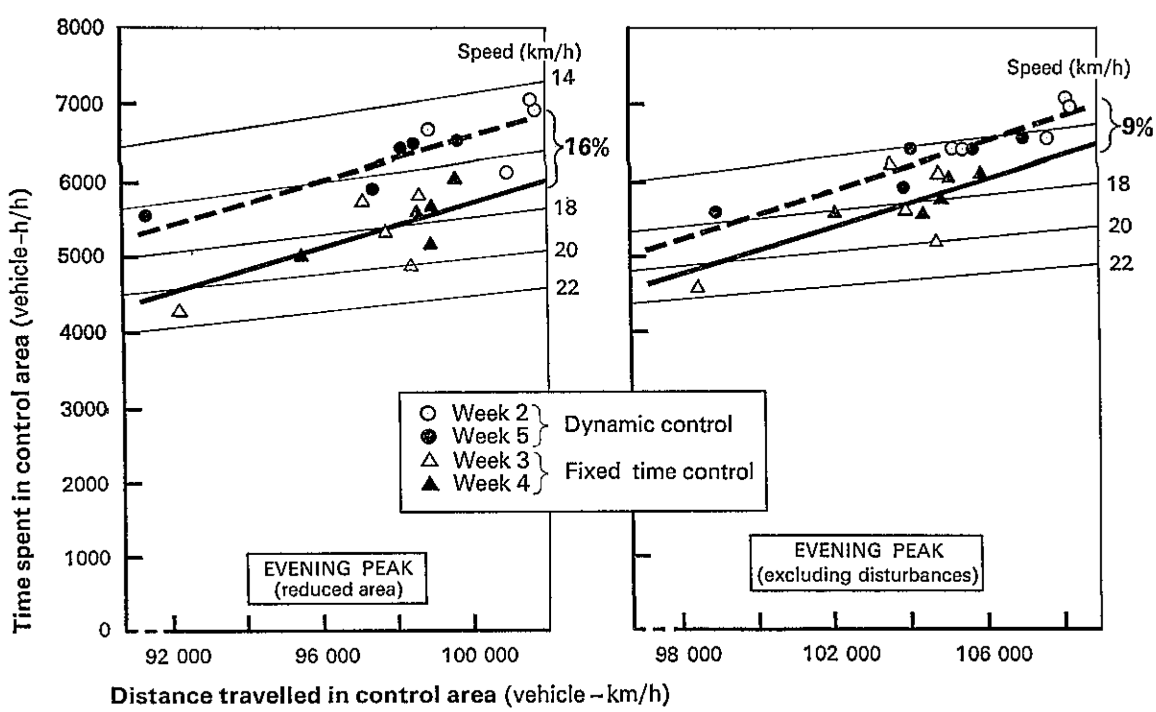


Fig. 29
Study of a dynamic signal plan generation system, evening peak



Chiswick. A queue of about a mile long containing several hundred vehicles regularly occurs where the motorway merges from three lanes to two lanes. The capacity of the merge appears to be about 4000 veh/h but this figure varies for reasons that are not yet entirely understood. Shock waves in the flow occur spontaneously within the two-lane section, but the evidence as to whether this effect produces a drop in capacity (as has been observed in tunnels) is so far inconclusive. Despite this overload at the merge, the journey time during the morning peak from Parkway to Chiswick on M4 is always shorter than along the alternative A4 route; under normal circumstances the average journey times are about 10 minutes and 20 minutes respectively.

Loop detectors spaced 400 m apart have been installed in each lane of M4 at two sites. Data from them are being analysed to see if congestion and accidents between such detectors can be detected reliably using pattern recognition techniques and other methods.

The Department of the Environment has agreed to designate 18 km of the western approaches to London as an experimental corridor to form part of the International Corridor Experiment project under the Organization for Economic Co-operation and Development (OECD). In this context, a corridor consists of a length or lengths of motorway together with the all-purpose roads forming the surrounding network, and the aim of the project is to promote international co-operation in research on traffic control strategies and associated problems. The British corridor includes the sections of M4 and A4 referred to above.

2.2.3 Road pricing equipment

The production costs of vehicle equipment which might be used in both on- and off-vehicle road pricing systems have been evaluated in some detail. The estimates lie between the limits shown at the bottom of Fig. 30. The lowest figure, estimated by an independent assessor (McMichael Ltd.) applies to the vehicle identification unit which is designed to operate in an off-vehicle road pricing system. The cost of a clockwork driven on-vehicle meter with a built in automatic meter reading facility would be significantly higher than those of any other instrument and work on this development has now ceased for the time being.

A battery operated meter is potentially the most competitive of the on-vehicle types and the evaluation of the life of batteries for this application is being continued at the Royal Aircraft Establishment. The solid electrolyte battery is receiving particular attention.

Figure 30 also shows some results of a detailed study carried out at the Laboratory of the probable costs of operating a road pricing system in an urban area. The average annual cost of equipping regular road users in a congested city, which represents the major cost in such a scheme, is given as a function of vehicle equipment cost and fitting charges. A regular user is defined as an individual who travels in the priced area once a fortnight or more. Restricting the issue of vehicle equipment to this category reduces the cost of implementing a road pricing scheme significantly. The question of whether it is economic to recover or abandon equipment when vehicles change hands can be seen from Fig. 30 to depend on the relation between equipment costs and fitting charges.

In parallel with the work relating to system costs the Laboratory has also carried out an analysis of the data transmission links and central computer requirements of an off-vehicle metering system operating in the same urban area and for the same class of road user described earlier. This analysis has shown that the computer requirements can be met by present generation equipment and that the data rates are consistent with present practice, see Table 7.

Industrial contracts have been placed for the development of driver indicators (McMichael Ltd.), roadside equipment (The Decca Navigator Co.) and the (Plessey Co.) for an off-vehicle recording system. Complementary work at the Laboratory includes a study of the economic implications of a driver indicator and the feasibility of recoverable vehicle identification units.

Laboratory scale trials of both on- and off-vehicle equipment continue. Promising figures for the reliability of data transmission from vehicle to roadside are now being obtained.

2.3 Traffic Systems Section

2.3.1 Junction design

Significant progress has been made during 1971 in work on improved junction designs exploiting the 'priority to traffic from the right' rule. A further major track experiment has been

Fig. 30
Vehicle equipment costs

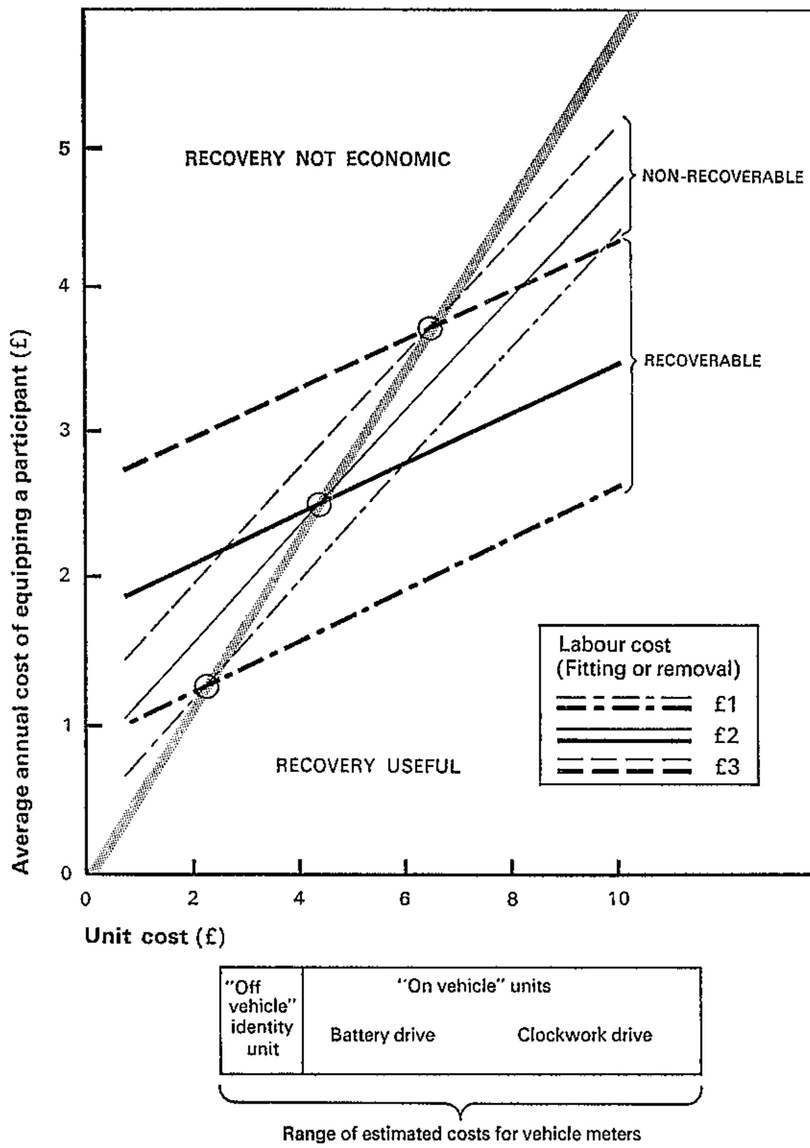


Table 7: Estimates of data rates in an off-vehicle recording system

Link-in network	Maximum rates identities/hour	Equivalent data rate	Typical rates possible
Vehicle to roadside receiver	2000 per traffic lane	—	—
Roadside receiver to telephone exchange	12,000 per eight-lane road	240 bits/second	1000 bits/second
Exchange to computer centre	120,000	2400 bits/second	2400 bits/second
Computer to backing store	600,000	1·33 kilobytes/second	120 kilobytes/second

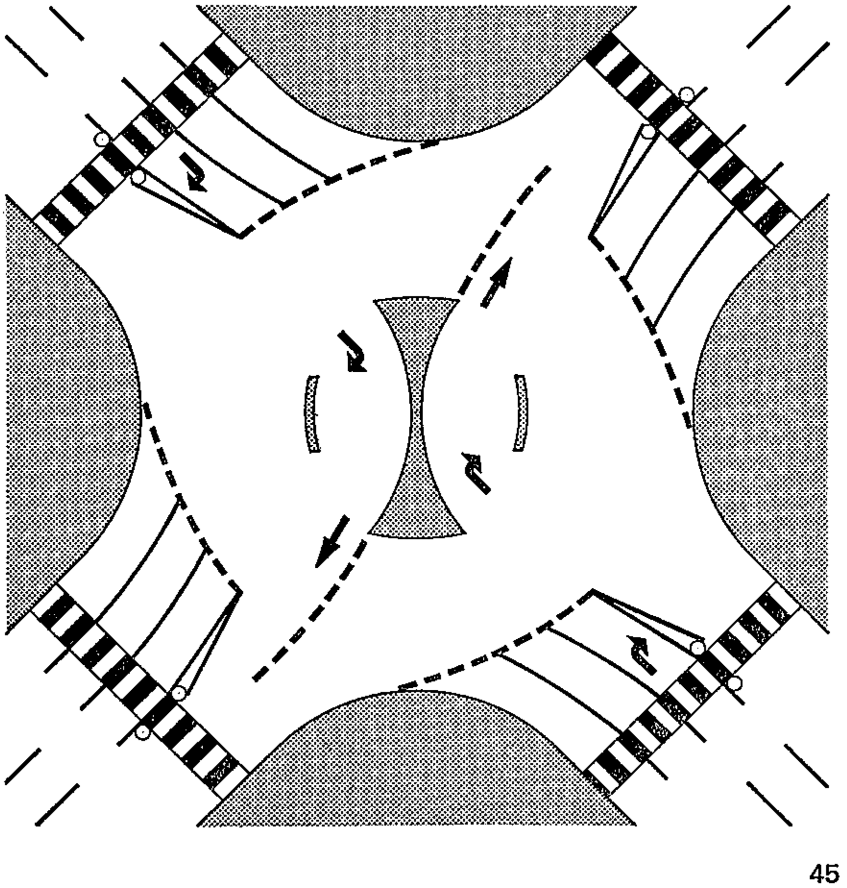
carried out, and several experiments at sites on public roads have shown the potential of the new designs. Information has also been collected to enable the accident rates of the new junctions to be compared with the rates at the more conventional designs.

2.3.2 Public road experiments

Following the successful conversion in June 1970 of a four-way signal controlled intersection at Upton Cross in Dorset to a double mini-roundabout, five other conversions of a similar nature have been carried out.

One of these, undertaken by the borough engineer at Colchester in June 1971 was a design for a scissored junction on the A12, in which a large single roundabout was replaced by a double mini-roundabout. A resulting increase of about 20 per cent in capacity was observed. The remaining four conversions, at Welwyn Garden City, Bridgwater (two) and Truro, involved the replacement of traffic signal control with a 'hollow island' design, similar to that illustrated in Fig. 31. This arrangement can be regarded as the equivalent of a single central island large enough to prevent straight across movements (and therefore high speeds), through which two channels are provided for the opposing right-turning movements from two of the approaches. The effect of this layout is to eliminate the conflicts between these two right turns by allowing a non-hooking turn, and to shorten their path within the junction. In two out of three cases, where this layout has been tried, increases in capacity have been observed immediately after the conversion. No measurements were made at Truro, but the preliminary indications suggest that accidents have been reduced.

Fig. 31
Welwyn Garden City—final layout 'hollow island'

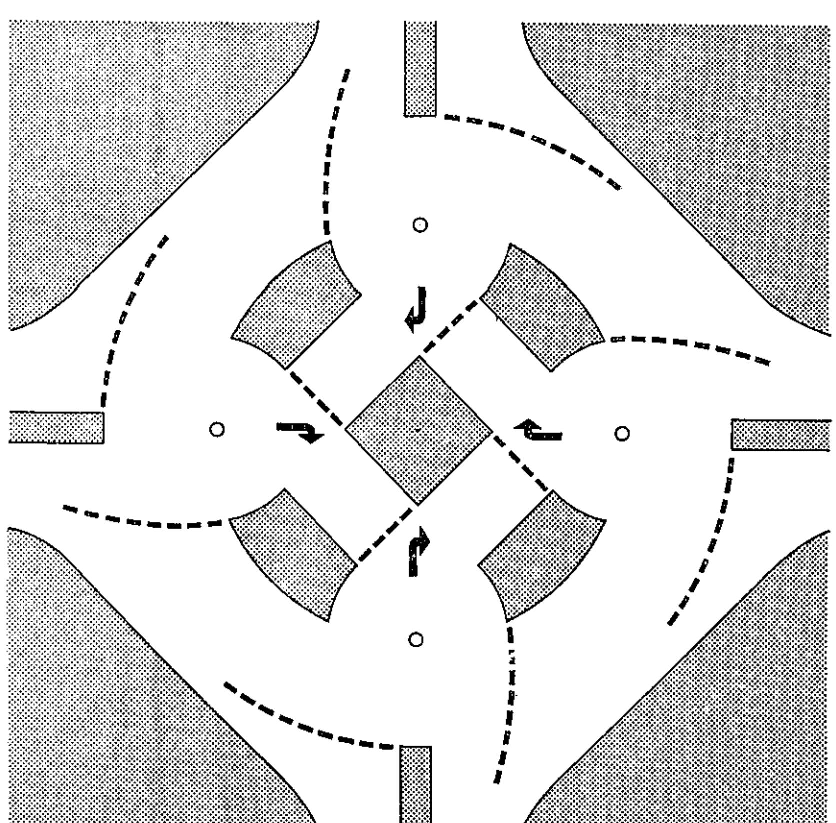


Development of these more complex arrangements is in its early stages but the recent track experiments (see next paragraph) have indicated the potential of layouts which reduce right-turning conflicts to the minimum by allowing non-hooking turns on all axes.

2.3.3 Track experiment

A programme of experiments was carried out on the research track on six days in June and July, with about 300 cars taking part. This was a preliminary investigation into the capacity of large junctions, including some types which could form parts of grade-separated interchanges. Four basic junction outlines were considered (a six-way, two four-ways, and a three-way) with various layouts utilizing the offside priority rule. The results revealed a number of problems associated with large junctions and there are apparently situations where the use of a single mini-roundabout design does not give the highest capacity. By comparison, tests showed that a considerable increase in capacity (30 per cent in one case) could be obtained by treating the junction as a 'ring' of three-way mini-roundabouts, as shown in Fig. 32. As a result of these experiments it is hoped to test some such layouts on the public roads during 1972.

Fig. 32
Track experiment—ring of four three-way mini-roundabouts



3.1 Accident Analysis Section

3.1.1 The use made of police accident data

Increasing use is being made of the data from Stats 19, which are the forms sent to the Department by the police for every injury accident. Over a quarter of a million injury accidents each year are recorded at RRL on magnetic tape for computer processing. The tabulation and retrieval of the data are now working well. Requests for tabulations or plots of accident sites are being received by Accident Analysis Section at the rate of 12 a month. The Directorate of Statistics and other DOE divisions also produce tabulations from Stats 19 data, making the total of requests each month about 25, ranging from simple tables to requests involving up to a thousand tables. Though most tabulations produced at the Laboratory arise from its own programme of research, about one in five are requested by other organizations such as universities, vehicle manufacturers and branches of the Department concerned with housing and highways. All these enquiries are additional to those which can be answered by reference to the yearly publication *Road Accidents*, which contains some 30 tables reviewing the accident situation.

During 1971 special attention has been paid to the quality of the data and to informing users of any limitations of the tabulations. A note has been issued for this purpose supplementing the explanatory booklet Stats 20.

An important use of Stats 19 is to highlight situations which require attention or are not generally understood, as in the following examples:

1. About 1 per cent of accidents occur in fog, 2 per cent when snowing and 15 per cent when raining; the remainder occur in dry weather (although the roads may not be dry).
2. About 2 per cent of fatal injury accidents and 1 per cent of fatal and serious injury accidents occur on motorways.
3. About 12 per cent fewer people were killed or seriously injured during the affected hours of the first two winters of British Standard Time than expected for Greenwich Mean Time.
4. About 330 people were killed in accidents in which vehicles struck lamp standards during 1970.
5. A total of 145 motorcycles (including scooters, mopeds, and combinations) with 17-year-old riders were involved in fatal accidents in 1970.
6. About 7 per cent of pedestrians killed or injured are not on the road but on footpaths or verges.
7. Young car drivers incur a higher proportion of their total casualties at night than do older drivers, partly because they drive more during those hours. As casualty rates are higher at night this makes a small contribution to their higher casualty rate. If travel by young drivers (i.e. those under twenty-five) was distributed over the day in the same way as that of older drivers their casualty rate would be about 10 per cent lower than it is, but it would still be more than two and a half times that of older drivers.

3.1.2 Participation in OECD Road Research Programme

1. Research Group S7 (the effects of speed limits outside built-up areas). A report reviewing past work on the effects of speed limits and examining the possibility of future trials has been drafted.
2. Working Party on Standardization of International Accident Statistics. This working party has recommended improvements in the classification of accidents and their severities in order to improve the comparability of international road accident statistics.

3.1.3 Benefits of the Road Safety Act 1967

Part One of this Act and the accompanying procedures for detecting alcohol in the breath and body came into effect on 9 October 1967 and preliminary figures of casualty reductions after its introduction were given in *Road Research 1968*,[38] pp. 15–17 and *Road Research 1969*,[5] pp. 44, 45. In assessing the effect on road safety it was assumed that, if the Act had not been introduced, the downward trend in casualty rates per 100 million vehicle kilometres during the four years 1963–66 (due to various other measures and traffic changes) would have continued into the next few years. The rates for 1967 and later years were predicted on this assumption and then applied to the recorded traffic volumes in those years to give 'expected' numbers of casualties. Figure 33 illustrates the process (for total casualties), leading to the following approximate savings in 1967–70 shown in Table 8.

Table 8: Approximate reductions in casualties (expected minus actual) in Great Britain attributable to the Road Safety Act 1967

Year	Killed	Total casualties (including killed)
1967	875	25000
1968	1440	43000
1969	770	28000
1970	730	16000

The savings were greatest during the first complete year's operation of the new law but even after four years' operation were still considerable. They were proportionally greatest in Wales and least in Scotland but no obvious explanation for this was found. In the first 12 months the drop in fatal and serious injuries was greatest between 2200 hours and 0400 hours on Saturday nights (pedestrians 36 per cent, others 44 per cent) and almost as great between the same hours on Fridays; on other nights the average drop was smaller (pedestrians 11 per cent, others 19 per cent). Reductions between 0400 hours and 2200 hours were much smaller (10 per cent or less).

Reports from coroners showed that the proportion of motor vehicle drivers and riders killed who had more than 80 mg of alcohol per 100 ml of blood fell from 25 per cent in the ten months before October 1967 to 15 per cent in the next corresponding ten months; by 1970 this percentage had risen to 20 per cent.

These casualty reductions were not attributable to less traffic, which fluctuated to the normal small extent, or to less drinking of alcohol, the national consumption of which continued to rise.

The above results were included in a more detailed paper given at an international OECD Symposium.[39]

3.1.4 The 'Give-Way' rule at roundabouts

An advisory rule that vehicles entering a roundabout should give way to those already on it has been in operation since November 1966. In some few cases the rule did not apply, precedence being given to traffic on one or more of the entry roads; in these cases the requirement for traffic on the roundabout to give way was indicated by markings on the road surface. The results of a before and after study at 55 of the exceptions and the remainder are given in Table 9.

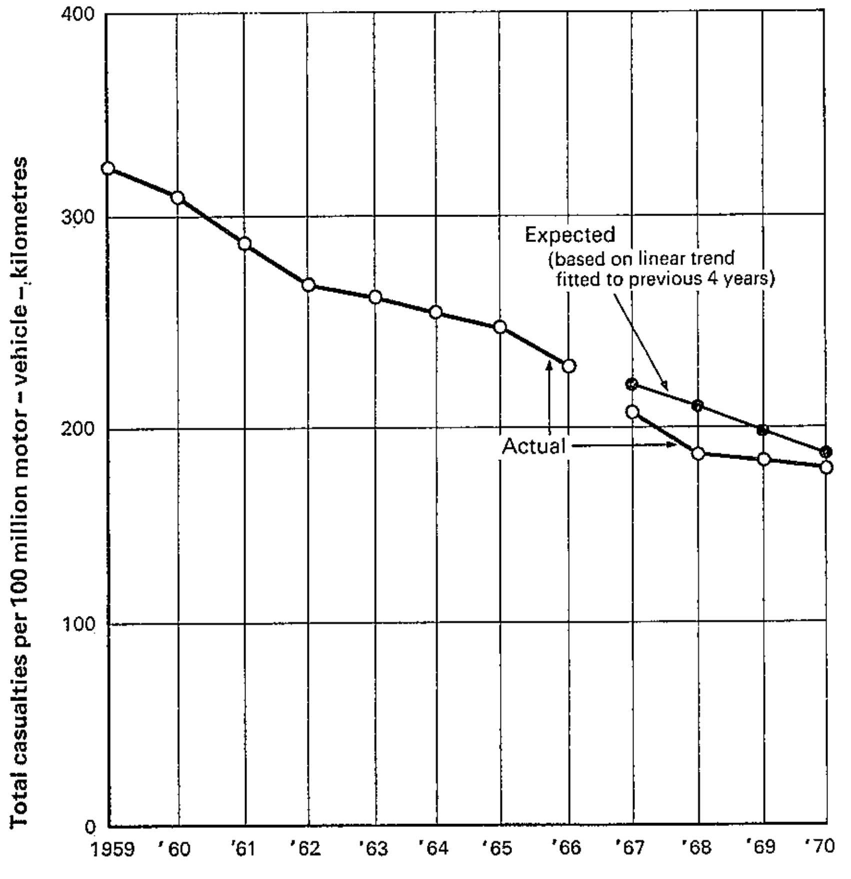
At the roundabouts where the rule applied the number of fatal or serious accidents or casualties either separately or combined were not significantly less (at the 5 per cent level) than would have been expected from the trend in the whole country. Earlier results were given in *Road Research 1968*,[38] p. 78. However, this does not necessarily mean that the 'Give-Way' rule had no safety benefits at these roundabouts as the information on slight injury and non-injury accidents was not available. Reductions in traffic delays at some roundabouts where the

Table 9: Accidents and casualties in Great Britain before and after the introduction of the 'Give-Way' rule

		Accidents			Casualties		
		Fatal	Fatal or serious injury	Total injury	Killed	Killed or seriously injured	Total casualties
Whole of Great Britain	Before	10 663	128 361	438 092	11,497	155,972	583,201
	After	9 593	119 601	400 754	10,370	144,710	531,769
All roundabouts in Great Britain, excluding those marked as exceptions	Before	82	1 589	..	88	1 808	..
	After	62	1 466	..	63	1 669	..
At 55 roundabouts marked as exceptions to the 'Give-Way' rule	Before	4	51	240	4	60	299
	After	2	34	180	2	38	230

Before = January 1965–June 1966 inclusive.
After = January 1967–June 1968 inclusive.
.. = Not available.

Fig. 33
Trend in total casualty rate 1959–70



rule was in use experimentally have already been noted (*Road Research 1962*,[40] p. 16).

At the 55 roundabouts where the rule did not apply and road markings were used instead the total number of casualties was about 16 per cent fewer than expected (reduction significant at 5 per cent level); fatal and serious casualties combined were 32 per cent fewer (reduction significant at about 6 per cent level). These improvements are likely to have been enhanced since the study was completed because upright posts with 'Give Way' signs were subsequently installed to supplement the exceptional markings.

3.1.5 Accidents at rural junctions

Work is in progress on experimental siting of islands and signs at simple crossroads. Plate 10, for example, shows the view confronting a driver approaching on a minor road. This junction was originally a simple intersection of two-lane roads. Small islands were constructed in the minor road, placed slightly to the left of the centre line so as to present an additional 'Give-Way' sign straight ahead of a driver approaching the junction. Each minor road approach was widened to allow large vehicles to pass on the left of the island.

The changes were designed to make drivers aware of the junction ahead and the regulatory sign. The layout should be generally applicable at this type of crossroads, and it requires a more deliberate sequence of actions to cross the major road or make right turns. Preparations have been made to extend this work to at least ten other junctions, with the object of measuring resultant changes in accidents, and so evaluating this type of layout as a low-cost alternative to the conventional staggered junction.

Information is being collected for comparative studies of other junction designs in non-built-up areas. Suitable junctions are being located from Stats 19 reports. Information obtained from these reports, from site inspections and from police accidents is being used to relate accident circumstances to fine detail of road layout.

3.1.6 'On-the-spot' accident investigation

Detailed investigations are being continued into the circumstances of accidents and the contributory factors, with these objectives:

1. To ensure that the Laboratory has a detailed grasp of the accident situation in one area of the country.

2. To estimate the relative importance of the different aspects of the accident situation and hence to put limits on the contribution that any safety measures might make.
3. To identify standards for vehicles, roads, and road users which need to be developed or modified, and to suggest future relevant research.
4. To develop background surveys and other studies which would help in understanding or analysing the accident situation.
5. To suggest remedial and preventive measures.

A report discussing the tentative findings from a preliminary set of 247 accidents is being prepared. The survey covers the 'D' Division of the Thames Valley Constabulary, a partly rural and partly suburban area. During the first 18 months investigation, a total of 639 accidents were studied in detail, though the full analysis of these data will be left until 1972 when over 1000 accidents will have been investigated. Of the 639 accidents, 50 per cent (319) occurred at intersections and one-third (215) involved the loss of control of vehicles. Of the 1139 motor vehicles involved in accidents, 845 (74 per cent) were cars; this is above the proportion for the country as a whole (just under 60 per cent). The proportions of two-wheeled and public service vehicles involved were low compared with the national average. There were only 41 pedestrians involved and this partly reflects the difficulty of reaching accidents involving pedestrians in time to study them.

Alcohol was thought to have played some part in 87 (13·5 per cent) of the 639 accidents. This is almost certainly an under-estimate of the presence of alcohol in drivers involved in accidents because it was not always possible to interview fully those concerned.

Accidents at 'black spots' were studied in particular detail, and similarities were found in accidents at each site. These suggested remedial measures which the local highway authority was able to implement.

3.1.7 Load-sensing valves on articulated vehicles

These valves are designed to cause brake pressures to vary with wheel loads and so to reduce the risk of wheels locking. British Road Services have co-operated in a trial of these valves by fitting them to the driven axles of 250 articulated vehicles (see *Road Research 1970*,[6] p. 50). The accident experience over a period of three years has been compared with that of a control sample of a similar number of vehicles without valves. In all there were 750 accidents on public roads and these have been analysed.

With the larger vehicles (30·5–32·5 Mg. gross vehicle weight), those with load sensing valves showed a marked reduction in jack-knifing accidents and no significant difference in other accidents. With the smaller vehicles (22·4–24·4 Mg. gross vehicle weight) the load sensed vehicles showed a reduction in jack-knifing, although the number of such accidents was small, and this reduction could have occurred by chance. However, the smaller load sensed vehicles had significantly more accidents than their control group. Further investigation found some evidence of faulty operation of the valves. No other factor was found which might account for this large rise in accident rate.

Evidently, better operation of the valves is needed before their universal adoption can be recommended.

3.1.8 Statistical techniques

The following are examples of help given on research work elsewhere in the Laboratory.

Paired comparisons. Six model street lighting systems were compared by means of subjective paired comparisons. Each subject observed all the 30 possible ordered pairs and expressed a preference for one member of each pair based on his subjective impression of the effectiveness of the lighting.

A mathematical model was constructed which arranges the six systems on a linear scale in order of preference. From this scale one can predict the probability P_{ij} that a subject will prefer system i to system j from the formula

$$P_{ij} = \Phi(\alpha_i - \alpha_j)$$

where α_i is the scale value corresponding to system i and Φ is the distribution function of a unit normal distribution (Thurston–Mosteller model).[41]

A computer program was written to calculate maximum likelihood estimates of the scale values and to determine significant differences.

It was found that six subjects were sufficient to arrange the six model lighting systems in order of preference (about 40 mins. observations per subject).

Cumulative normal models. A number of problems requiring these models have been dealt with, and the following is one example.

In an experiment on visual perception of forms (e.g. figures, letters, etc.) subjects were asked to determine the orientation of forms presented to them for short times, varying from 5 to 60 ms. They were of two types, simple or complex, and in groups of one or four (all of the same orientation). The numbers correctly orientated are shown in Fig. 34.

The mathematical model assumed a normal distribution for the threshold time of orientation of the single forms; the derived four-form curves were based on the assumption of independent mental processing of the four separate forms.

A further model postulating parallel processing of features gave a very good explanation of the difference between the simple and complex pairs of curves.

Spectral analysis. A spectral analysis has been performed on vertical profiles of surfaces on the research track, obtained from stereo photographs. The purpose was to relate the frequency of deformation of tyres passing over the surfaces to their frictional properties.

3.2 Vehicles Section

3.2.1 Injury investigations

Work continues on the causation of road accident injuries. About 900 vehicle accidents, 150 pedestrian accidents and 150 road accident fatalities have been investigated since the current accident-injury research programme began at the Laboratory.

Largely due to the introduction in 1966 of the high penetration resistant laminated glass windscreen in the USA attention has been focused on the relative merits of laminated and toughened glass windscreens. The injury-accident material collected at the Laboratory over the last seven years shows that amongst seriously injured front seat occupants of passenger cars involved in collisions, from any impact direction, toughened glass is about twice as safe as earlier versions of laminated glass (with a 0·38 mm interlayer) if minor injuries are excluded, and about 1·5 times safer if all severities of injury are included. The number of accidents investigated in which the windscreen was of the new high penetration resistant laminated glass is too small to allow a statistical comparison to be made, but the Laboratory results suggest that for cars in use on British roads the safety effectiveness of laminated glass windscreens with a high penetration resistant interlayer compared with toughened windscreens may not be as great as present American data imply. In accident-injury work the overall incidence of eye injury thought to have been due to toughened windscreen glass amongst a total of 1423 seriously injured vehicle occupants varied annually between nil and 1 per cent with an average of 0·6 per cent over a four-year period (1967–70). If only those cases are included in which the severity of injury was sufficiently great to reduce visual acuity permanently in the injured eye to 6/60 (on the Snellen Chart) or less, the incidence of eye injury was considerably lower (see Table 10). It has not been possible to confirm the increase in eye injury due to toughened windscreen glass recently reported from Europe.

3.2.2 Occupant protection

Results of the annual survey in London and the Thames Valley shown in Table 11 indicate that the usage of seat belts has remained substantially constant over the last three years although the percentage of cars fitted increased from 72 per cent to 87 per cent.

Investigations have continued into ways of encouraging the use of passive seat belts and into seat belt interlock systems that prevent the car being driven before the belt is fastened.

An evaluation of a number of such interlock systems has been carried out with particular emphasis on their operation, effectiveness and cost. The basic systems considered were interlocks acting either on the ignition circuit, the starter circuit, or the gear box.

The system which appeared to have the most potential, namely a starter interlock with seat sensors and a warning device, has been fitted to a vehicle for further assessment.

3.2.3 Commercial vehicles

Roll Tests. Articulated vehicles of given combination weights from 32·5 Mg. to 44·5 Mg. laden with container loads having their centre of gravity at the container mid points about 2·44 m from ground level were subjected to dynamic roll tests (using an outrigger to prevent overturning) on the test track (Plate 11)

Fig. 34
Cumulative distributions fitted to results of visual perception experiments

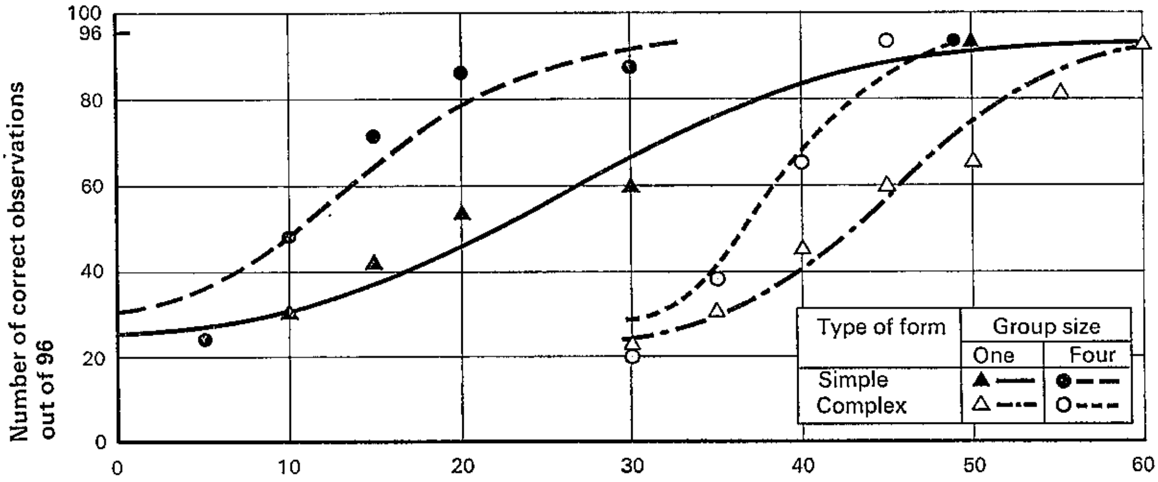


Table 10: Injury to the eye in vehicle occupants due to toughened glass windscreens (Total sample size, four years—1423 seriously injured vehicle occupants)

Year	No. of cases of eye injury due to toughened wind-screen glass	No. of seriously injured vehicle occupant casualties	Percentage of eye injury cases out of total number of seriously injured vehicle occupant casualties			
			Slight %	Severe: better than 6/60 % (a)	Severe: 6/60 or less than 6/60 % (b)	All severities
1967	—	325	—	—	—	—
1968	2	309	—	0·3	0·3	0·6
1969	4	357	—	0·5	0·5	1·1
1970	3	432	0·2	—	0·5	0·7
Total	9	1423	0·1	0·2	0·3	0·6

Slight injury: Superficial injury to the cornea.
Severe injury: Penetrating injury of the eyeball.
(*a*) With residual uncorrected visual acuity better than 6/60.
or (*b*) With residual uncorrected visual acuity less than 6/60.

Table 11: Percentage of front seat occupants of cars wearing seat belts in London and the Thames Valley

Class of road on which observation was made	Year of observation						
	1964	1966	1967	1968	1969	1970	1971
Motorways	9	15	16	23	28	34	30
'A' roads	7	9	11	19	20	21	20
Town roads	5	4	6	9	8	8	9
Central London	2	4	—	7	8	6	10
East London	3	4	—	5	5	6	3
Percentage of cars *fitted* with seat belts			28	52	72	82	87

Plate 1
The noise barrier along the south side at Heston

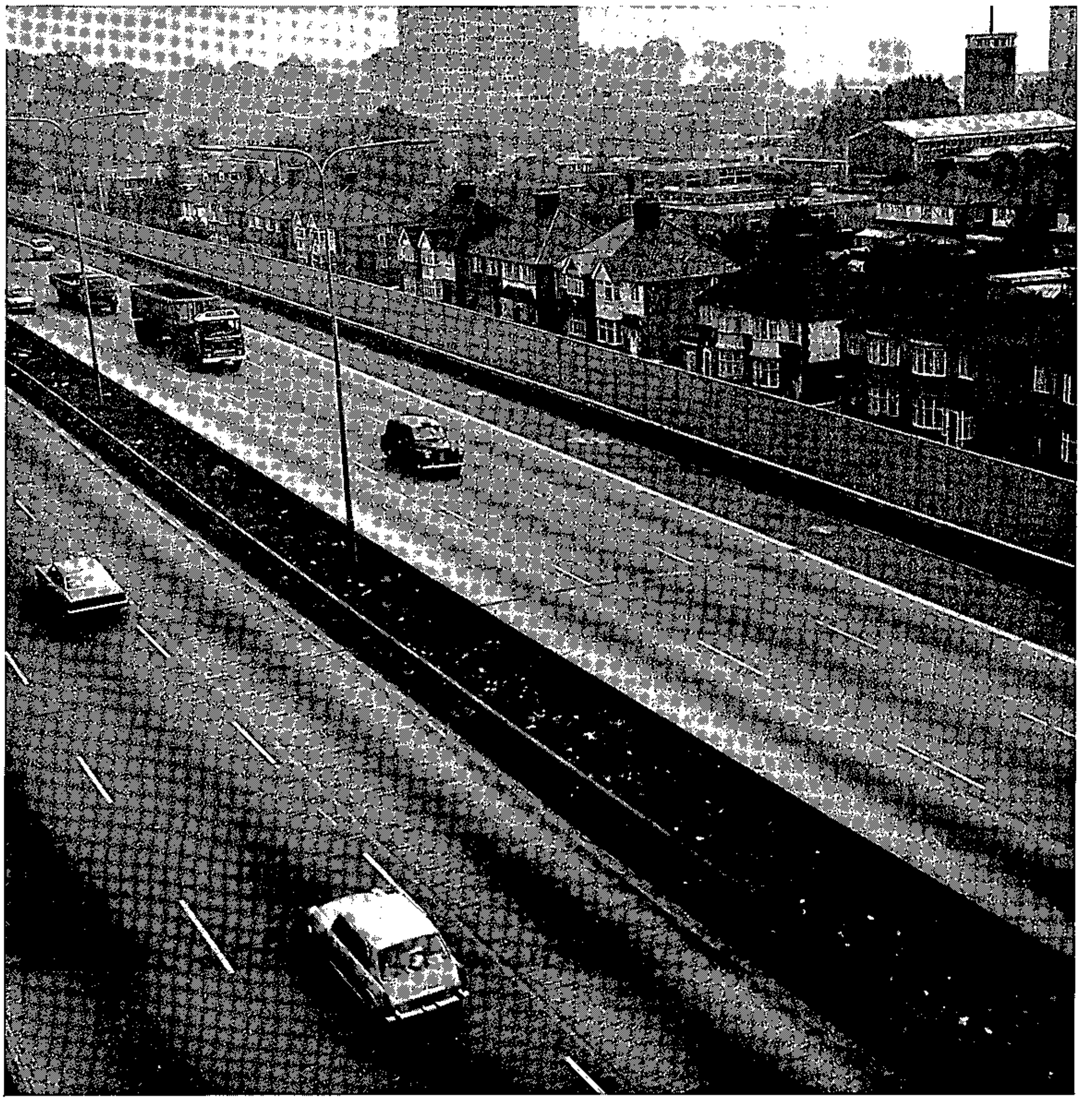


Plate 2
Channel tunnel ferry-train test rig

Plate 3
Interior view of test rig showing lower deck of double-deck train

Plate 4
Underside of vehicle submitted to salt splash corrosion test, without inhibitor, during winter 1970–71

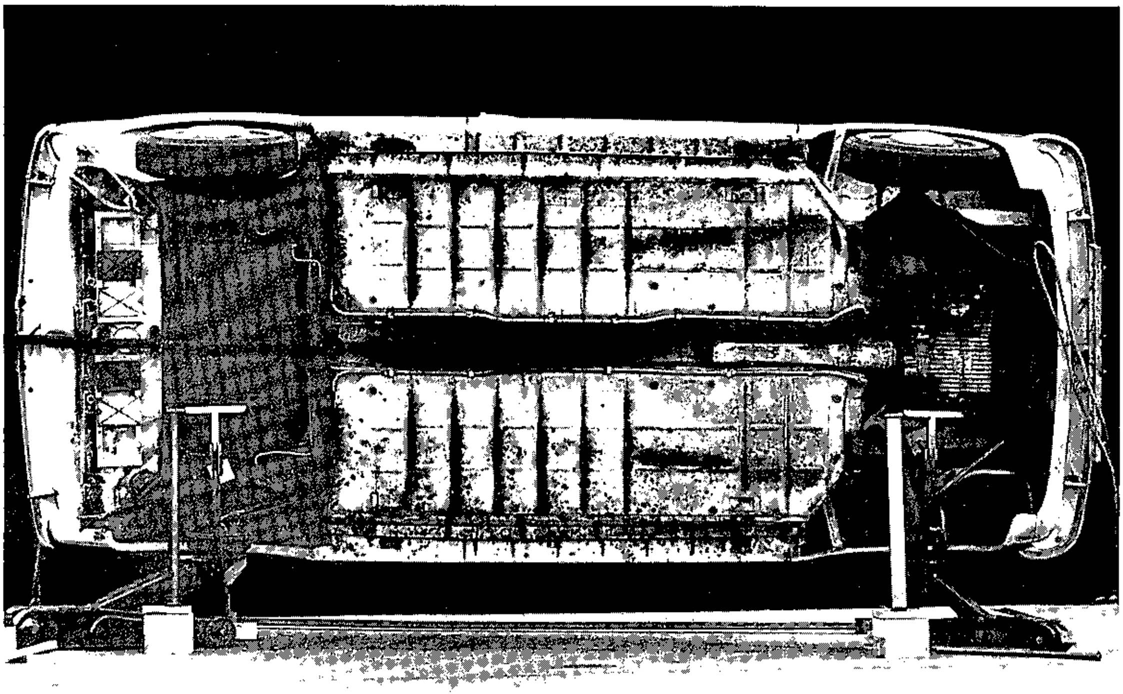


Plate 5
Underside of vehicle submitted to salt splash with added high-level of corrosion inhibitor during winter 1970–71

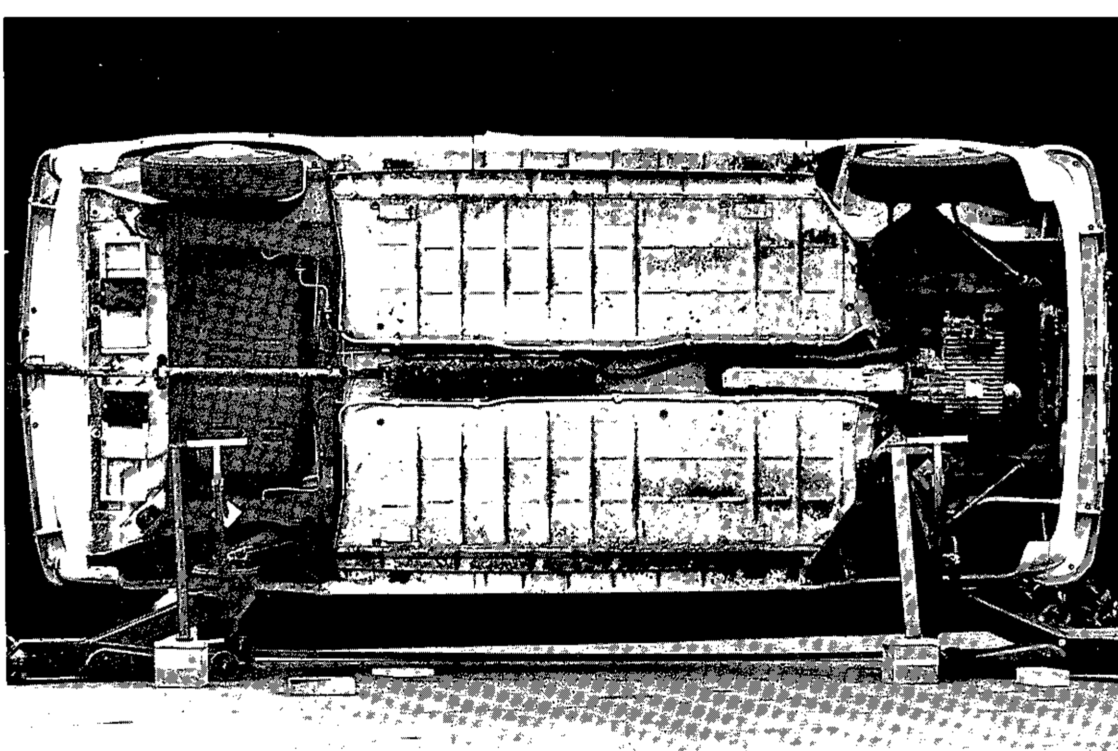
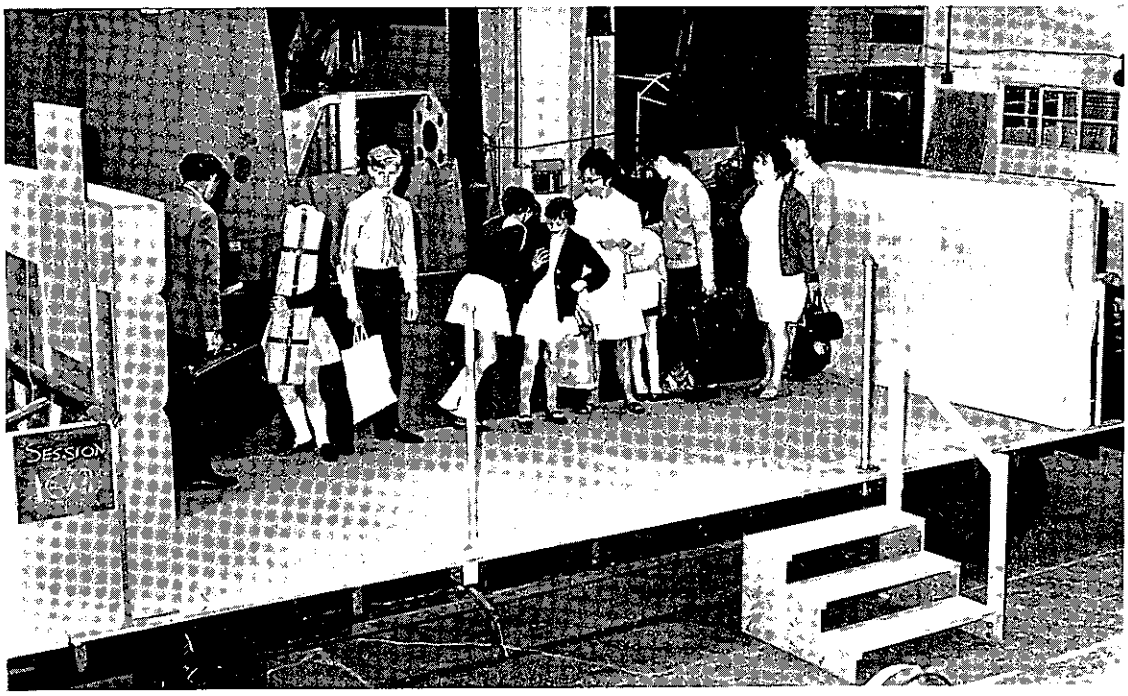


Plate 6
Experiments on comfortable acceleration range for pedestrian conveyors. Tests with families of RAE staff



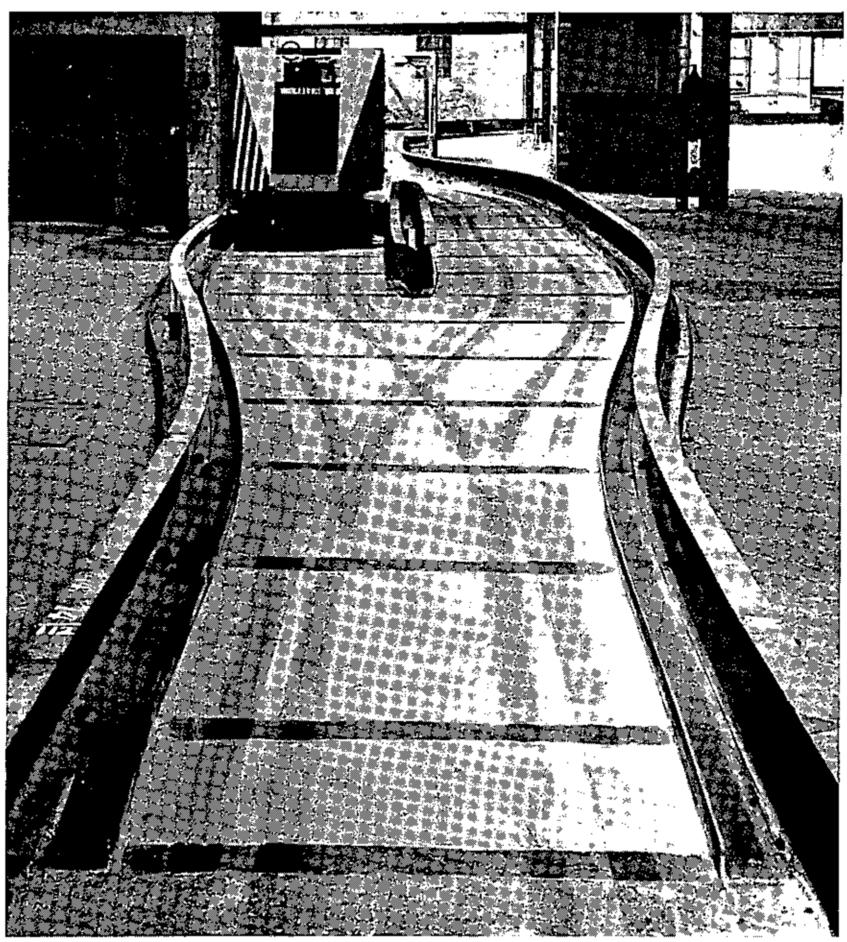


Plate 7
Experimental test track for small automatic vehicles, showing junction and experimental car

Plate 8
Power car for experimental Advanced Passenger Train under construction

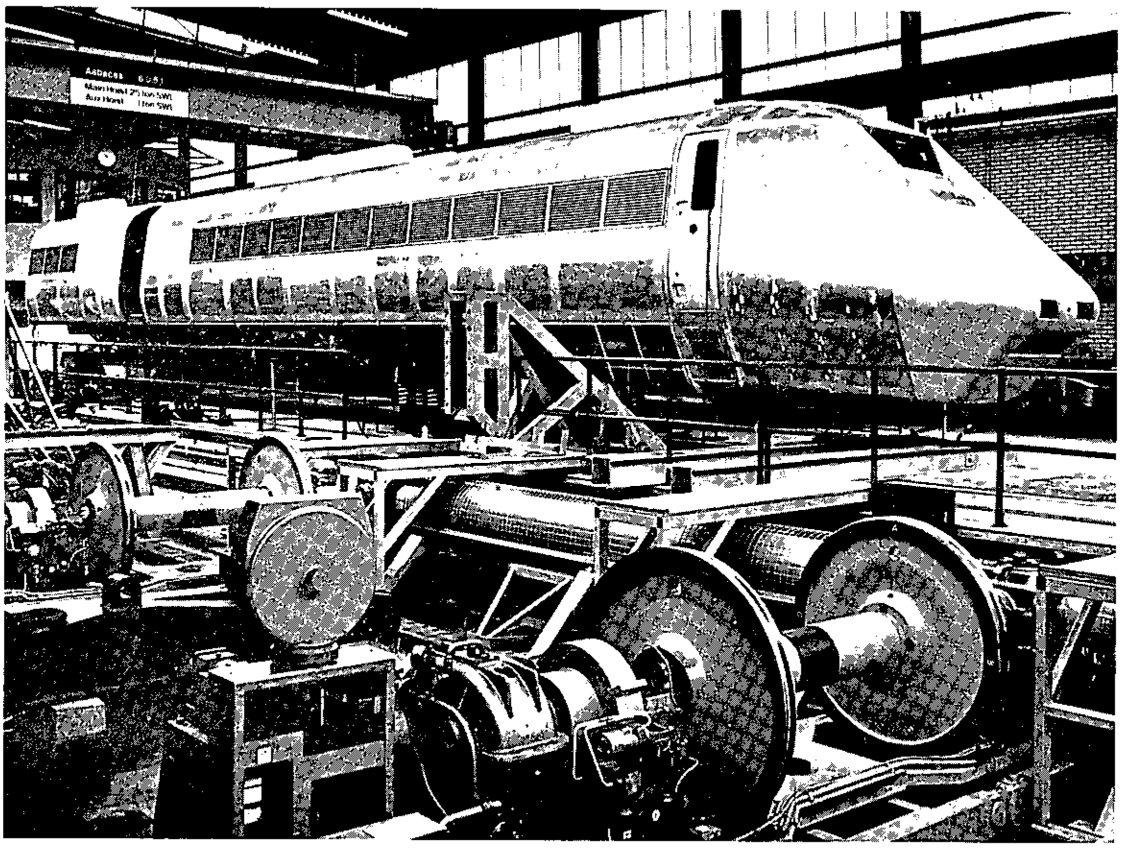


Plate 9
Experimental Hovertrain at the test track

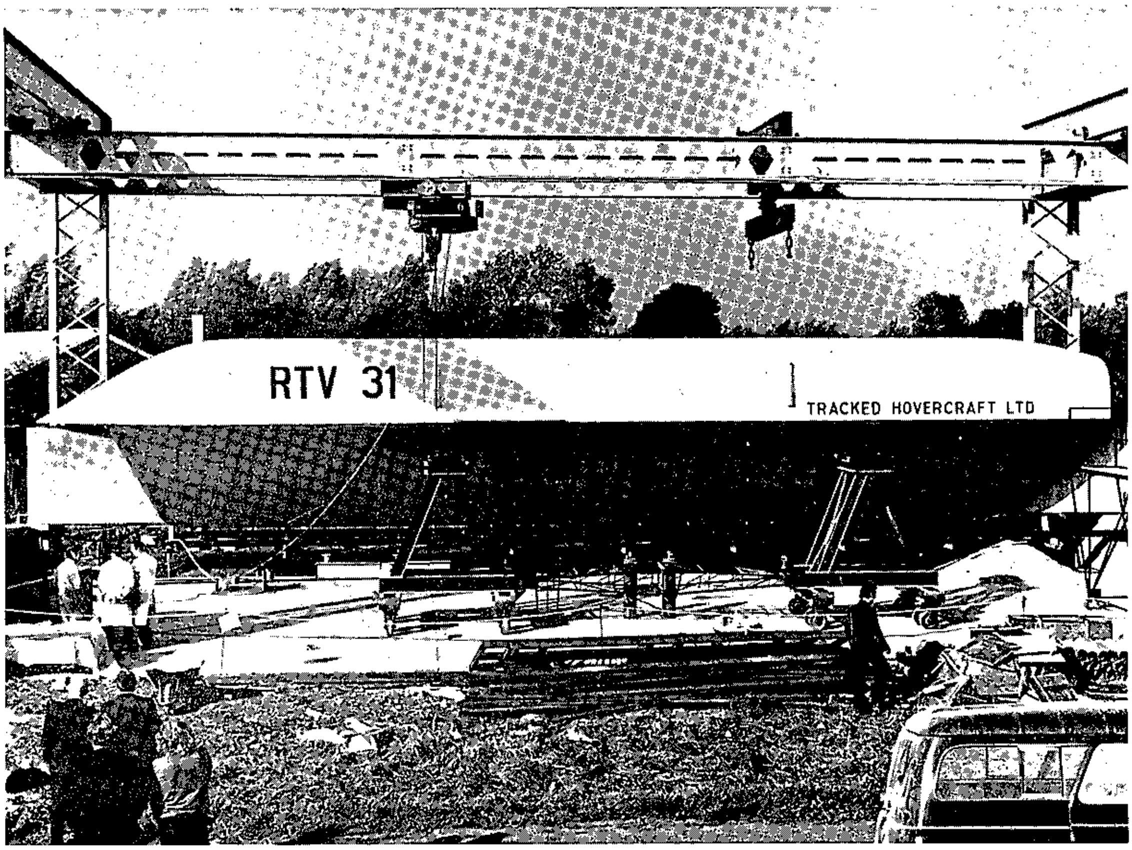


Plate 10
Experimental siting of islands and signs at simple crossroads

Plate 11
38.5 Mg gross weight articulated lorry in roll-over condition on dynamic roll tests showing outrigger and wheel lift device

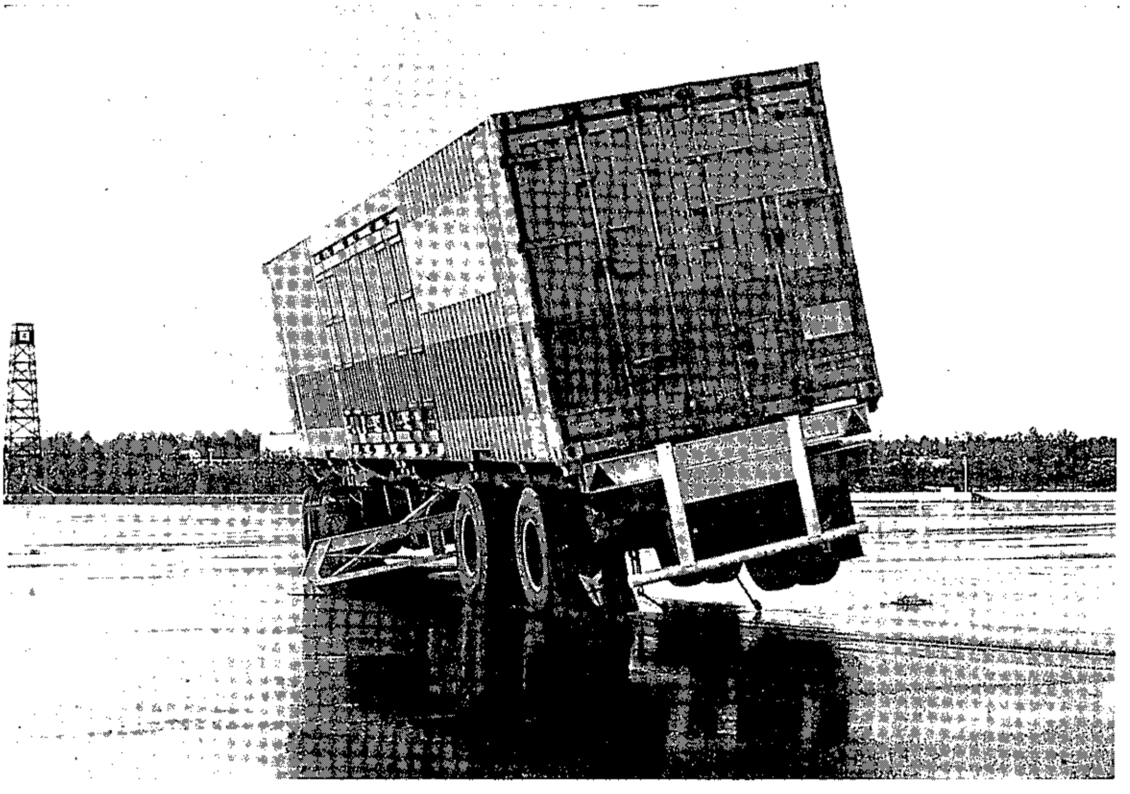


Plate 12
Tests on lorry tyres:
a case of rear end breakaway

Plate 13
(a) A group of children begin to cross the road. The 'leader' looks before crossing but does not stop at the kerb

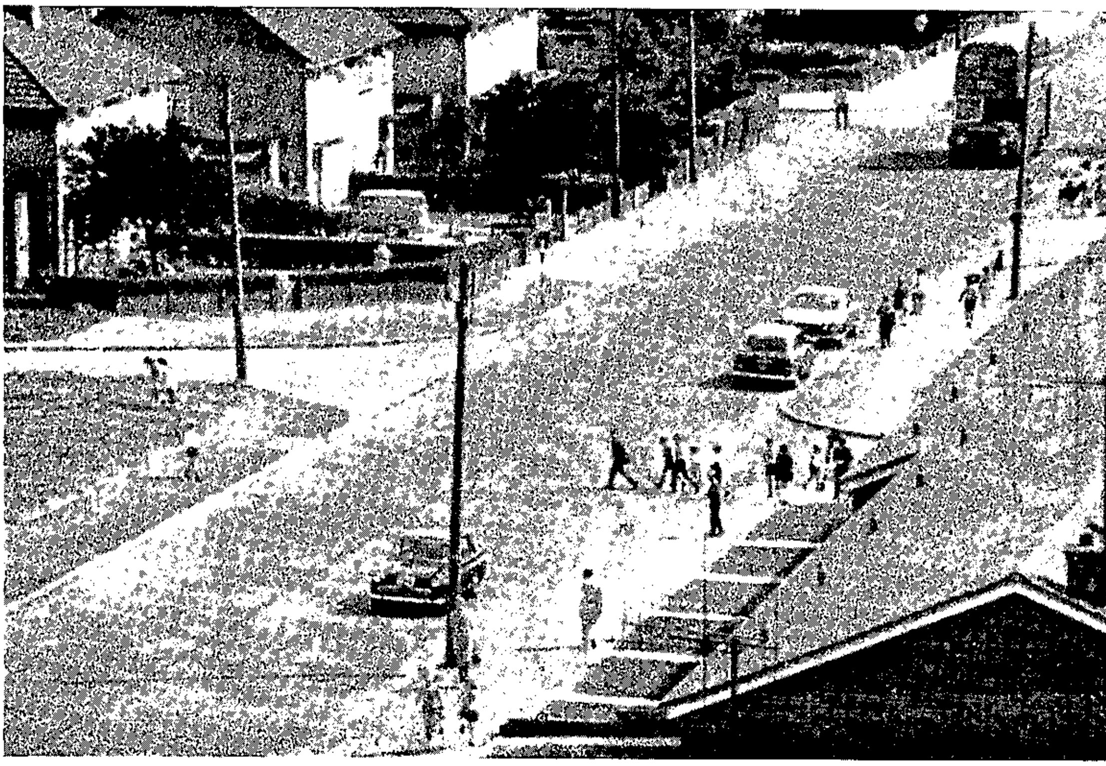


Plate 13
(b) The younger children follow the leader, without looking or stopping at the kerb

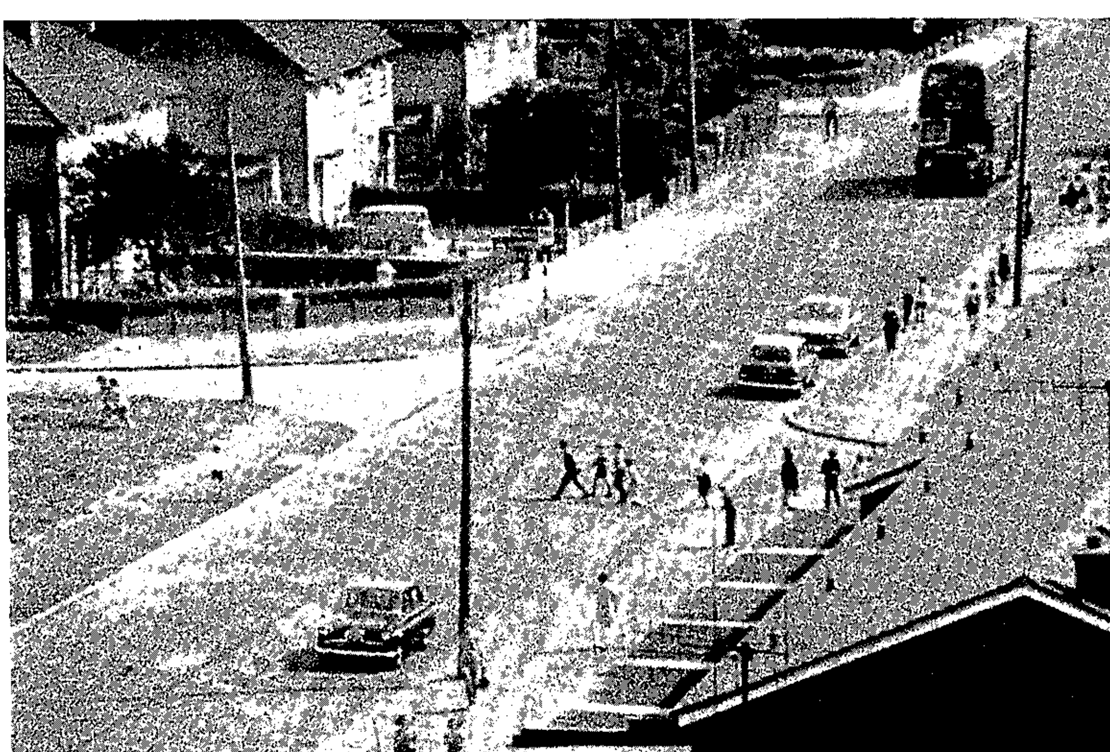


Plate 13
(c) The small girl originally at the back of the group has run on ahead

Plate 13
(d) The group arrives at the kerb. One child has been left behind and waits for the bus to pass

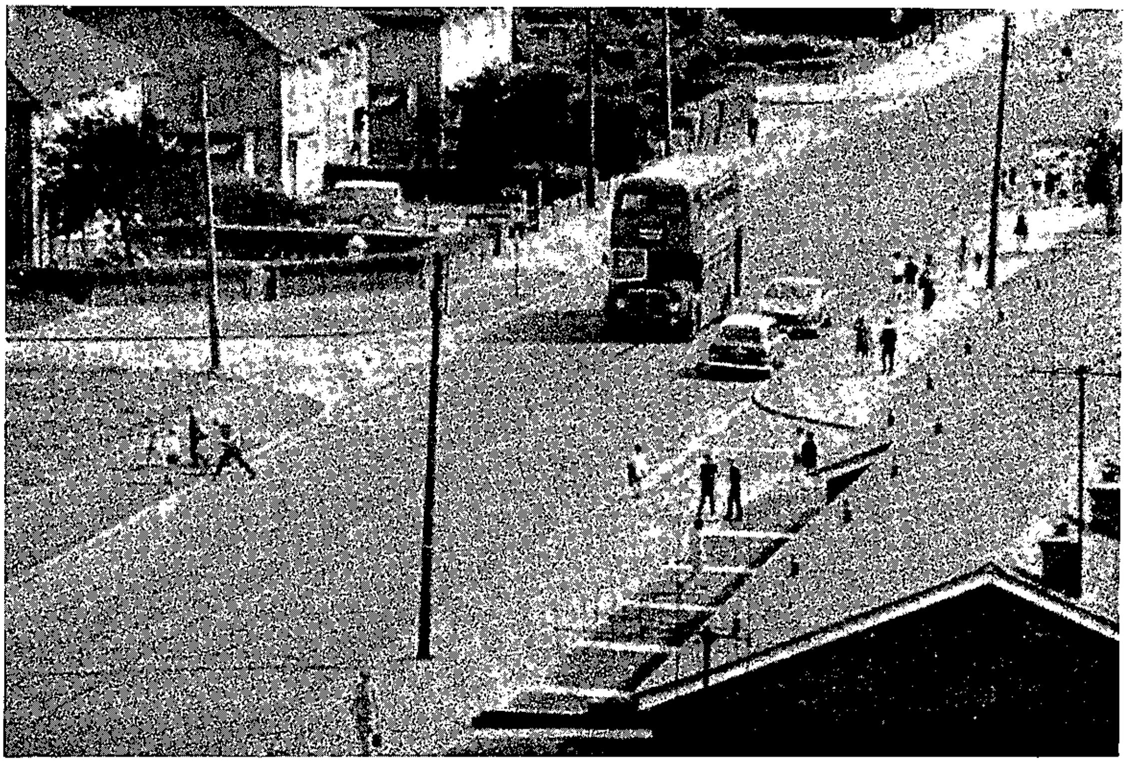


Plate 14

Electric steering actuator installation in Ford Cortina. The driver's 'dial-a-speed' control can also be seen on the right of the steering wheel

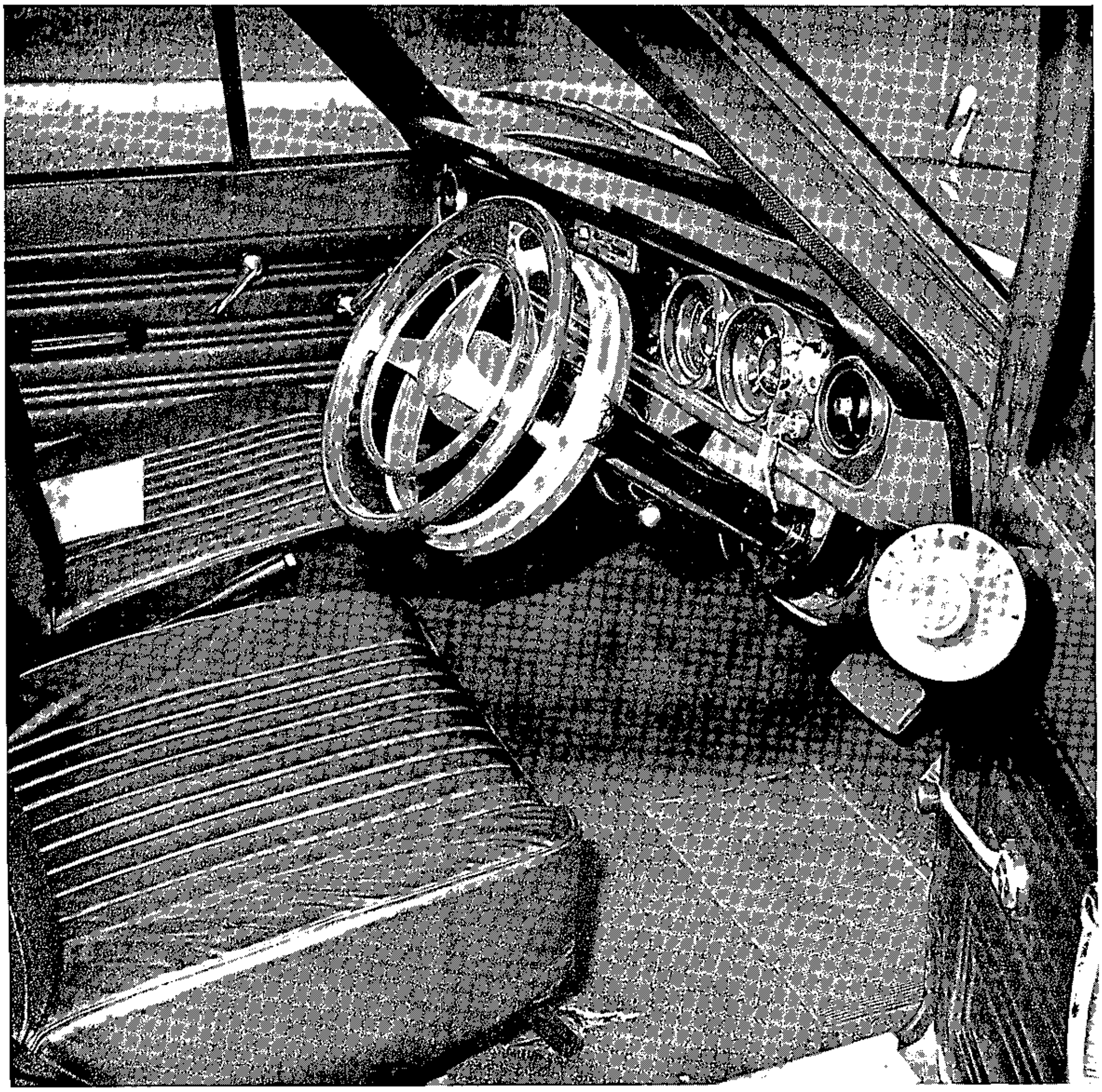


Plate 15
Instrumented shaping machine being used for rock-cutting research

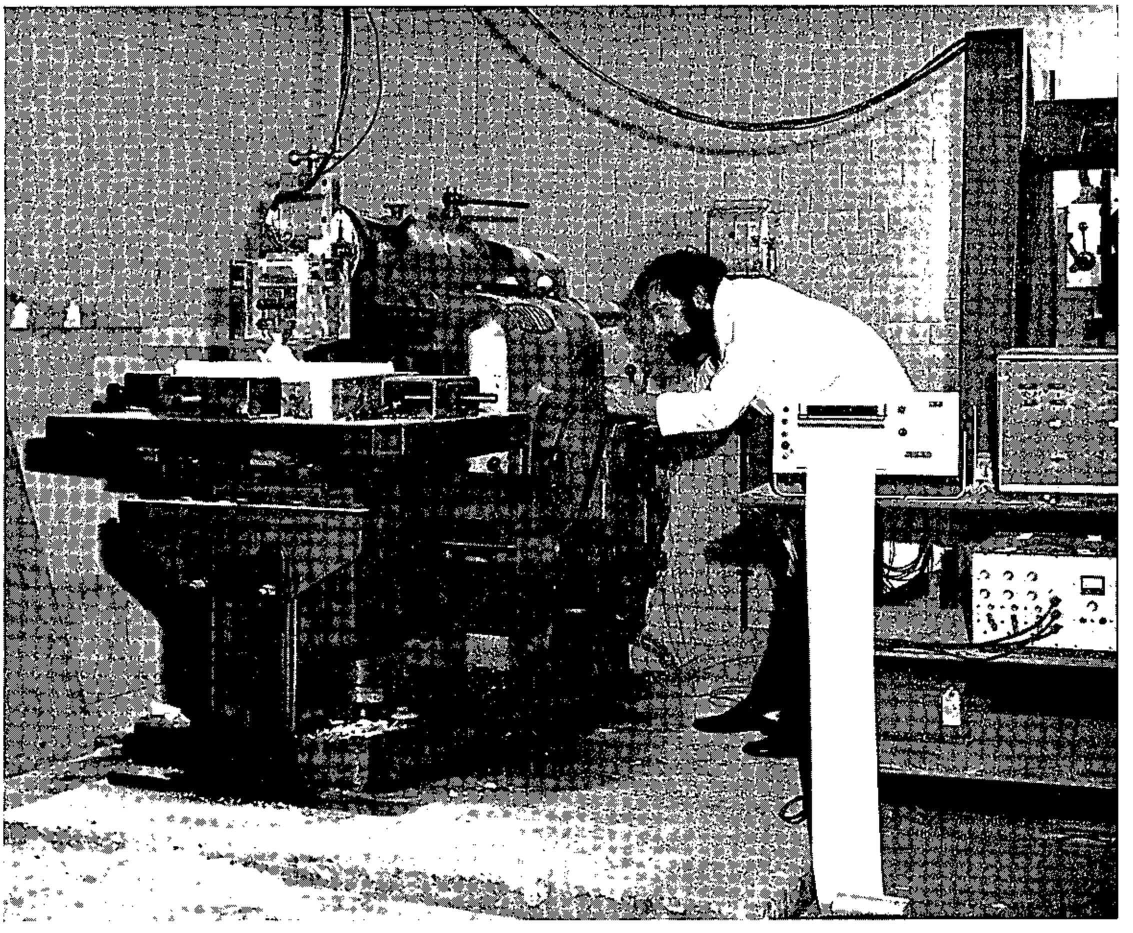


Plate 16
The 1 Mg double vibrating roller

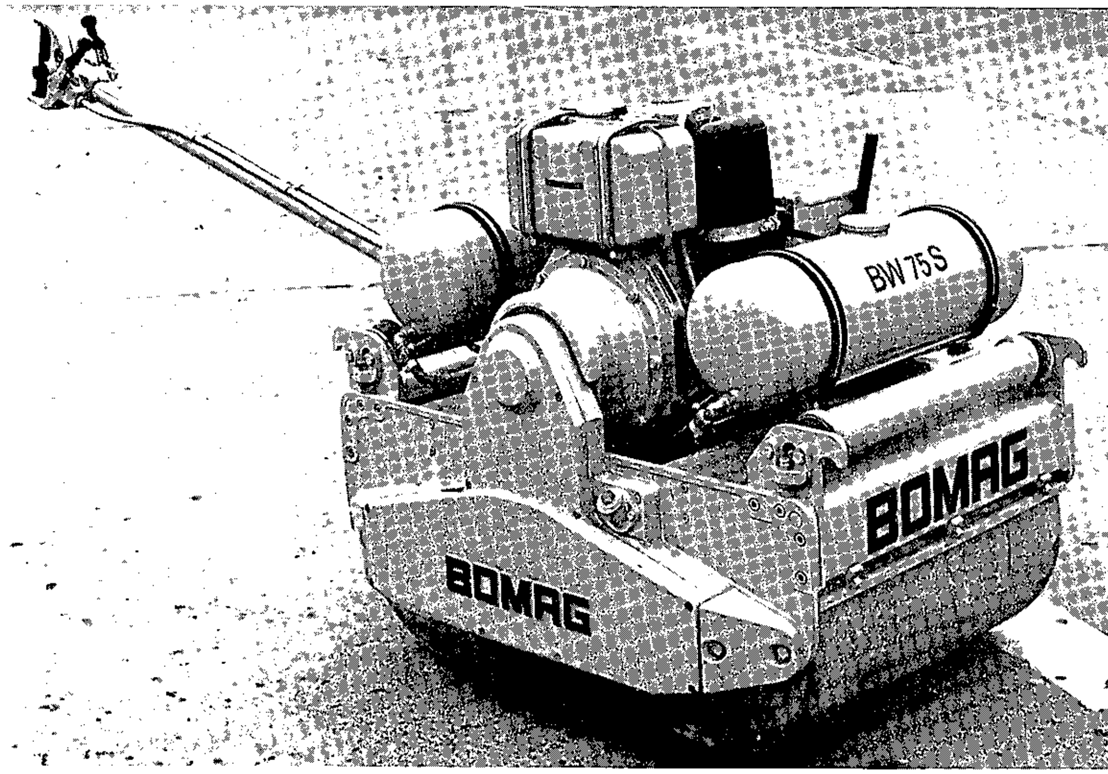
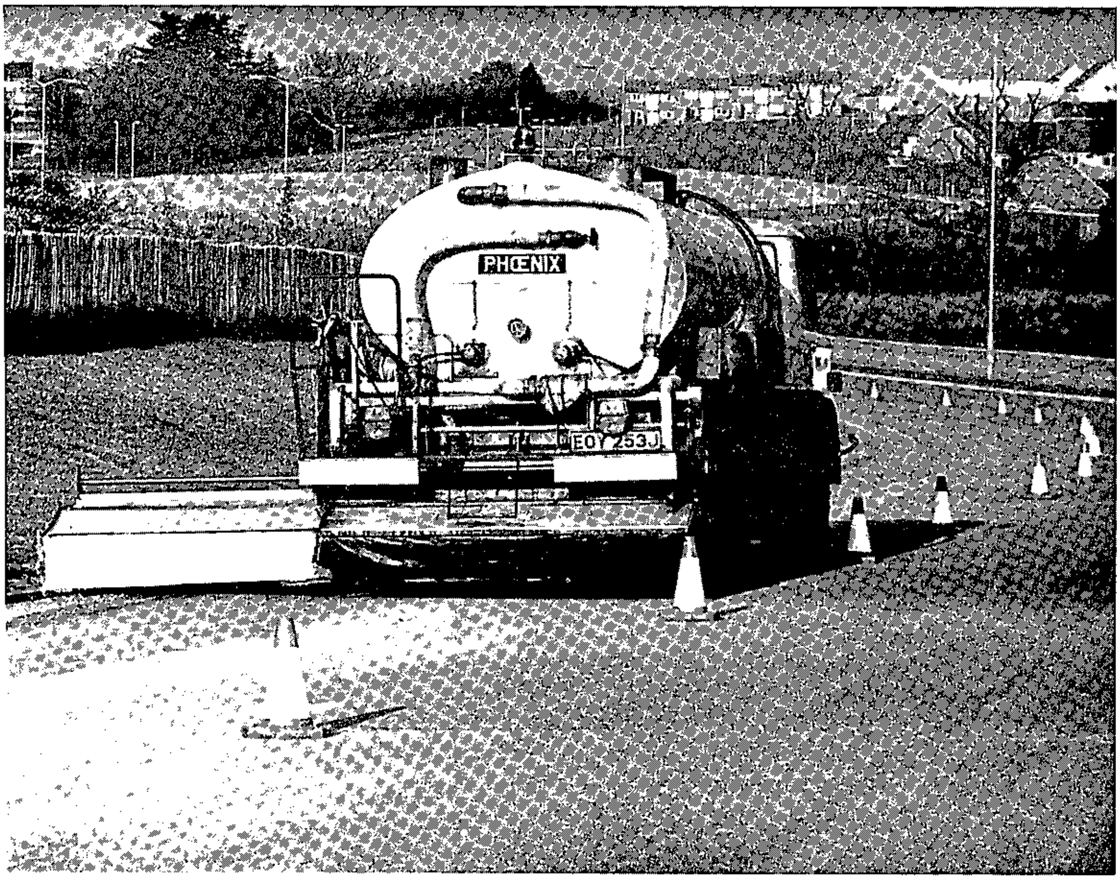


Plate 17
The 7.3 Mg double vibrating roller

Plate 18
Installation of earth pressure cells

Plate 19
Prototype variable-width distributor with the distributor fully extended



and static tests on a tilt table. Body roll angles, spring and wheel movements were measured and compared. The following results show good correlation between the static and dynamic tests suggesting that static tilt tests would be one useful criterion for roll-over.

G.V.W. Mg.	Dynamic		Static		
	Roll-over speed on 20 m radius km/h	Equiv. lat. acc. g	Angle of tilt at roll-over point	Equiv. lat. acc. g.	Equiv. speed on 20 m radius km/h
44·5	21·6	0·20	12·4°	0·21	23·0
32·5	24·8	0·26	15·7°	0·27	26·1
38·5	25·6	0·28	17·6°	0·30	27·6
32·5	26·4	0·29	18·9°	0·32	28·3

3.2.4 Standards for vehicle handling characteristics

One approach to the problem of establishing standards for the handling characteristics of cars is to study their behaviour in practical tests in which road accident situations are simulated. In an exploratory investigation of this type, a single driver put a group of 11 cars, with widely different physical characteristics, through two tests (a cornering test and a lane change test) on two different road surfaces (a dry high coefficient surface and a wet slippery surface) using two criteria—performance (maximum speed) and warning of impending failure (difference between maximum speed and the speed at which the driver sensed the beginning of loss of control).

There was a significant correlation between maximum speed in the curve test and the size of the vehicle (the larger cars tending to be the slower) on the dry surface whilst on the wet slippery surface there was no such correlation, speeds probably being limited by the friction available between tyre and road. Similar results were obtained in the lane change test and also when the warning criterion was applied, the amount of warning being very small.

Another approach to the problem is to study the basic response characteristics of the vehicle. One of the characteristics included in the USA specification for Experimental Safety Vehicles is the steady-state yawing response as illustrated in Fig. 35 which includes values for three popular British cars. The exclusion of the vehicles with characteristics which do not fall within the specification area cannot be justified at present on safety grounds.

3.2.5 Tyre/road interaction—wet road grip of lorry tyres

In conjunction with the Military Vehicle Experimental Establishment preliminary measurements have been made of the effectiveness in cornering and braking on wet roads of tyres designed for:

1. Use on roads (highway service tyres).
2. Use both on and off roads (dual purpose tyres).
3. Cross country work.

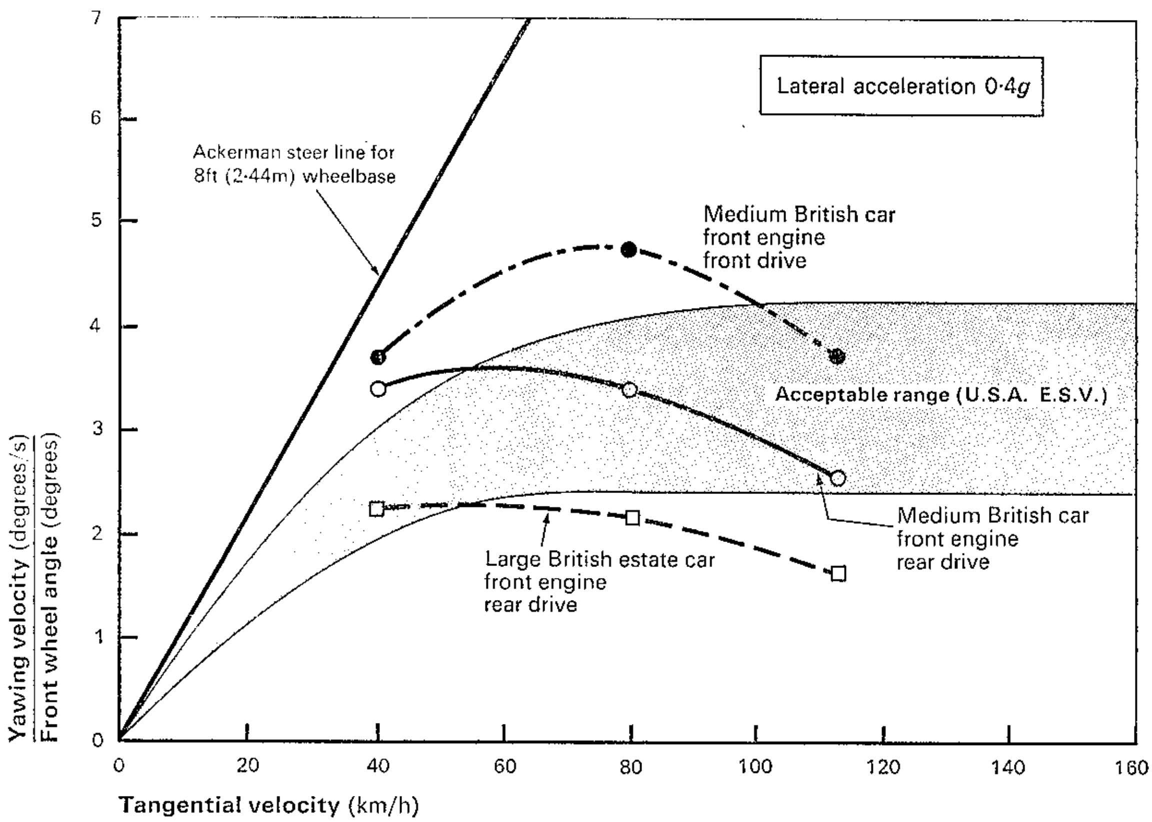
For comparison, measurements were also made on smooth lorry tyres and fully-patterned car tyres. For the tests on lorry tyres a vehicle carrying a load of 1 Mg, one-third of its rated load, was used (Plate 12).

The maximum lateral accelerations achieved at different speeds in cornering tests on wet mastic asphalt (a smooth polished surface) are shown in Fig. 36.

Locked wheel braking force coefficients for wet mastic asphalt (determined by braking the front wheels only) are shown in Fig. 37. Peak values show a similar spread. On wet rough polished surfaces (e.g. a macadam containing rounded gravel) the coefficients are higher and the differences somewhat smaller. The lorry brakes were not sufficiently effective to enable tests to be made on wet, rough, harsh surfaces.

It is clear that on wet smooth polished surfaces there are marked differences in the grip provided by different types of lorry tyre. To judge from the braking results even the best lorry tyre is less effective than a representative car tyre.

Fig. 35
Steady state yawing response characteristics of three British cars compared with the USA specifications for Experimental Safety Vehicles



3.3 Road User Characteristics

3.3.1 Behaviour of adult pedestrians

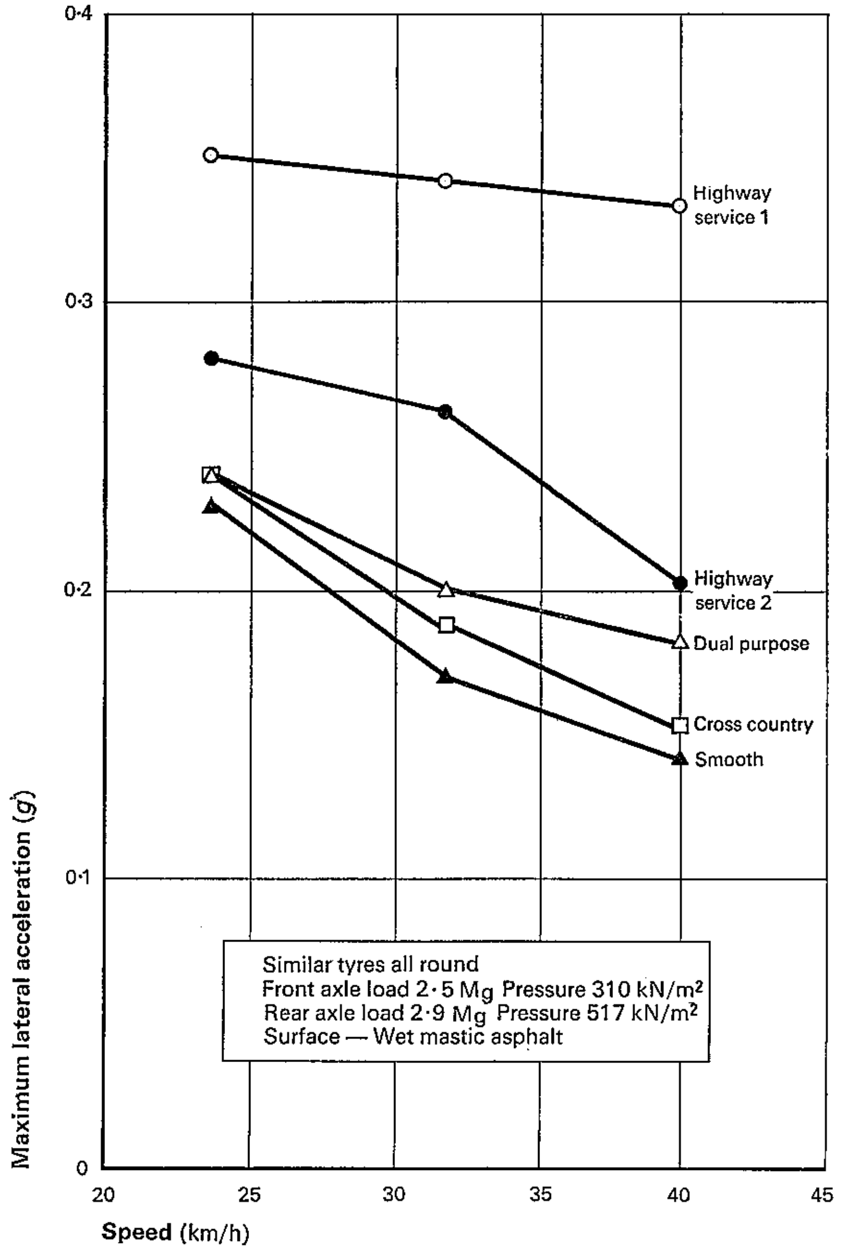
The behaviour of elderly pedestrians is being studied in comparison with that of younger adults. At present, information has been obtained on differences with age of such things as delay before crossing the road, crossing times and head movements made before and during crossing. Whereas it appears that the time delay before crossing increases with age the time spent actually crossing the road remains remarkably constant for all adult ages (see Fig. 38). Only for the very old (over 80) is there an indication of an increase. This finding is complemented by that indicating a change in the number of head movements with age (see Fig. 39). Whereas head movements before crossing increase in number with age those made while crossing tend to decrease with age. The pattern of behaviour of the elderly appears to be a long period of assessment of the situation before crossing, but after commencing to cross a concentration on completing the manoeuvre with little reassessment being made.

Results so far are from studies made on two lengths of fairly quiet shopping streets with traffic flows of the order of 700 veh/h. In these relatively quiet conditions there seems very little difference between the immediate traffic situations, such as the position and movement of vehicles, in which elderly and other adult pedestrians cross the road. However, in current studies being made at two further sites on busier shopping streets where vehicle flow is about 1000 veh/h and crossing the road is more difficult, differences between behaviour at different ages may well emerge. Information obtained on the other personal factors such as familiarity with road, ability to drive, etc. (see *Road Research 1970*,[6] p. 58) have not yet been analysed.

3.3.2 Behaviour and accidents of child pedestrians

As already mentioned in Part One, p. 12, research on child pedestrians is being carried out in three topics: the study of accident data, observations of natural behaviour, and the assessment of the exposure to risk of children. An analysis of accident data based on information from the normal police accident

Fig. 36
Tests on lorry tyres: results of cornering tests

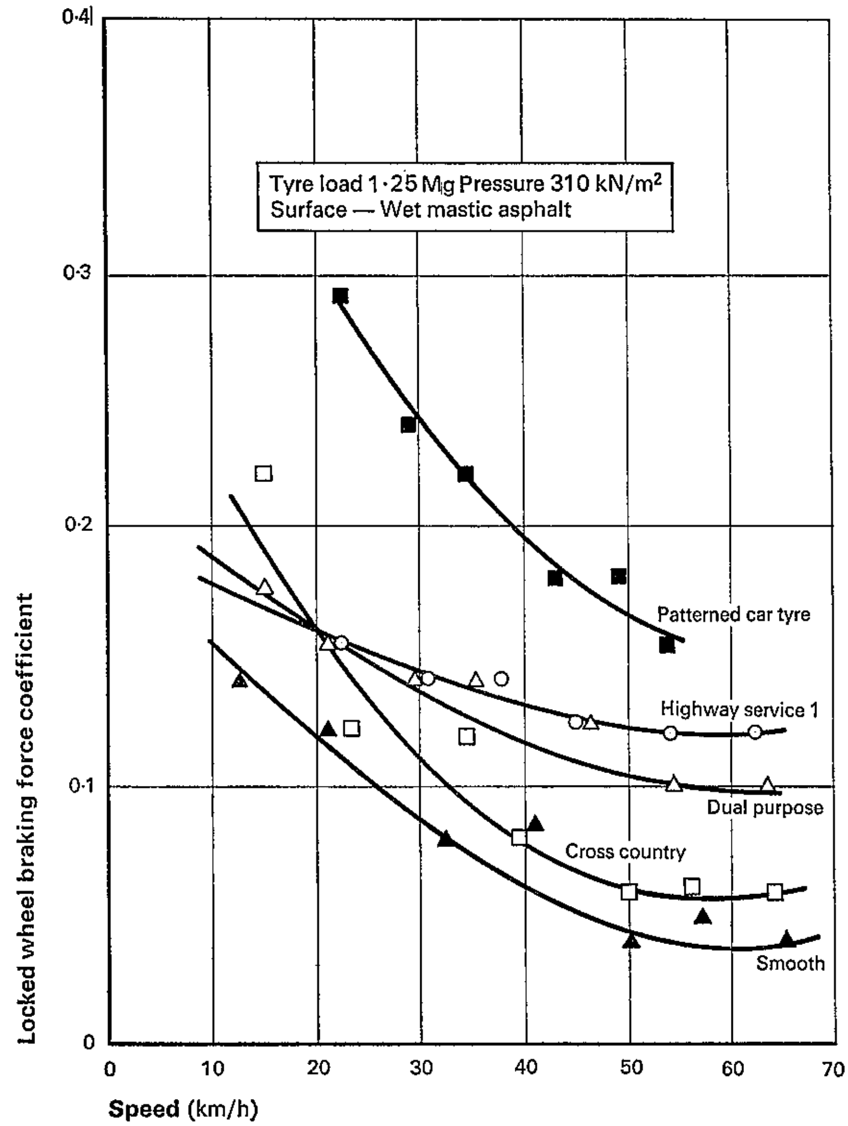


reports (Stats 19) supplemented by a specially designed questionnaire, collected by the Hampshire police, has confirmed that lack of attention on the part of the child is a major contributory factor in accidents to child pedestrians. The behaviour of children on the roads is being studied through the analysis of filmed records of different sites taken from concealed vantage points using time lapse cameras to identify situations leading to reduced attention to traffic. Aspects of behaviour being studied include whether or not the child stopped at the kerb, and for how long, the number and direction of head movements, crossing time and direction, the influence of parked vehicles, and the effects of accompaniment of the child (a typical film record is shown in Plate 13).

A pilot survey using a form of the moving observer technique was carried out in one typical residential estate in order to determine the numbers of children of different age groups out on the streets during the day (see Fig. 40). Information was also collected on the activities and accompaniment of the children, so that it may be compared at a later date with accident data. The survey was conducted during the school holidays and further surveys are planned to study the situation during term times.

A seminar on child pedestrians was held at the Laboratory in July 1971 to discuss research problems and to facilitate the exchange of ideas among workers in this field. Research on children's road behaviour and personality carried out under contract at the University of

Fig. 37
Tests on lorry tyres: results of front-wheel braking tests



Southampton has recently been completed. Work on the acquisition and nature of perceptual and judgemental skill in the road crossing task is continuing under contract with the University of Nottingham.

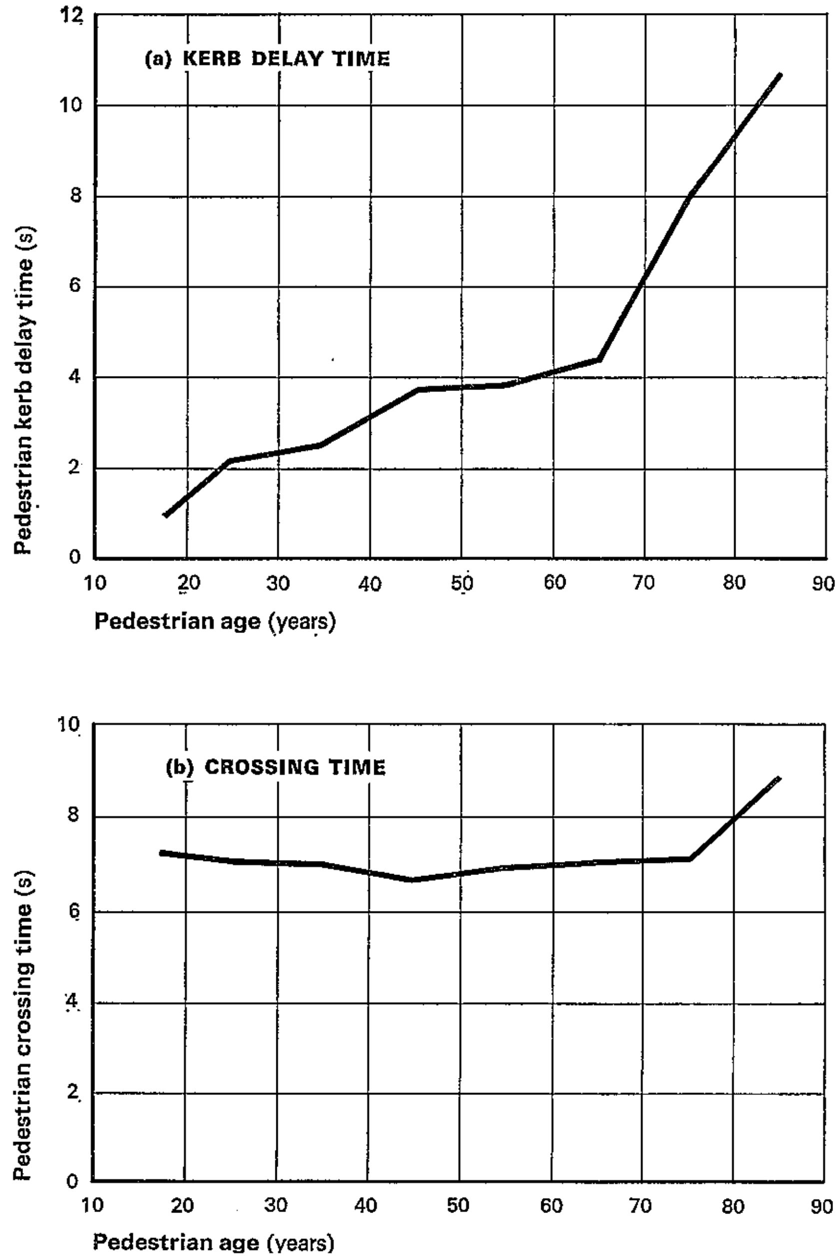
3.3.3 Vehicle conflicts at junctions

In studies concerned with safety of junctions, work is continuing to assess the value of vehicle 'conflicts',[42] as a criterion of safety. Conflict situations occur where there is imminent danger of collision if vehicle movements remain unchanged (see *Road Research 1970*,[6] p. 56). Comparison of the number of conflicts observed during a given time period at each of five different junctions, showed that placing them in order of importance depending on the number of conflicts resulted in the same order as that obtained by arranging them by the number of recorded accidents at each junction (see Table 12). Thus there is some evidence that frequency of conflicts provides a criterion to judge between the safety of different junctions. However, it is also evident that there are other factors present and that total conflicts only provide a crude comparison between junctions. Different types of conflict, e.g. those due to intersecting manoeuvres and those due to merging manoeuvres, appear to have different rates of injury accident production, as might be expected.

Table 12: Relation of observed conflicts to reported injury accidents at different junctions

Junctions	Conflicts observed per 10 hours	Accidents reported per 3 years
1	8	5
2	9	10
3	17	14
4	49	36
5	52	48

Fig. 38
Kerb delay and crossing time (for pedestrians crossing alone)



That they serve to identify accident locations within a junction has been further confirmed by detailed conflict studies at junctions other than the one referred to in *Road Research 1970,*[6] p. 56.

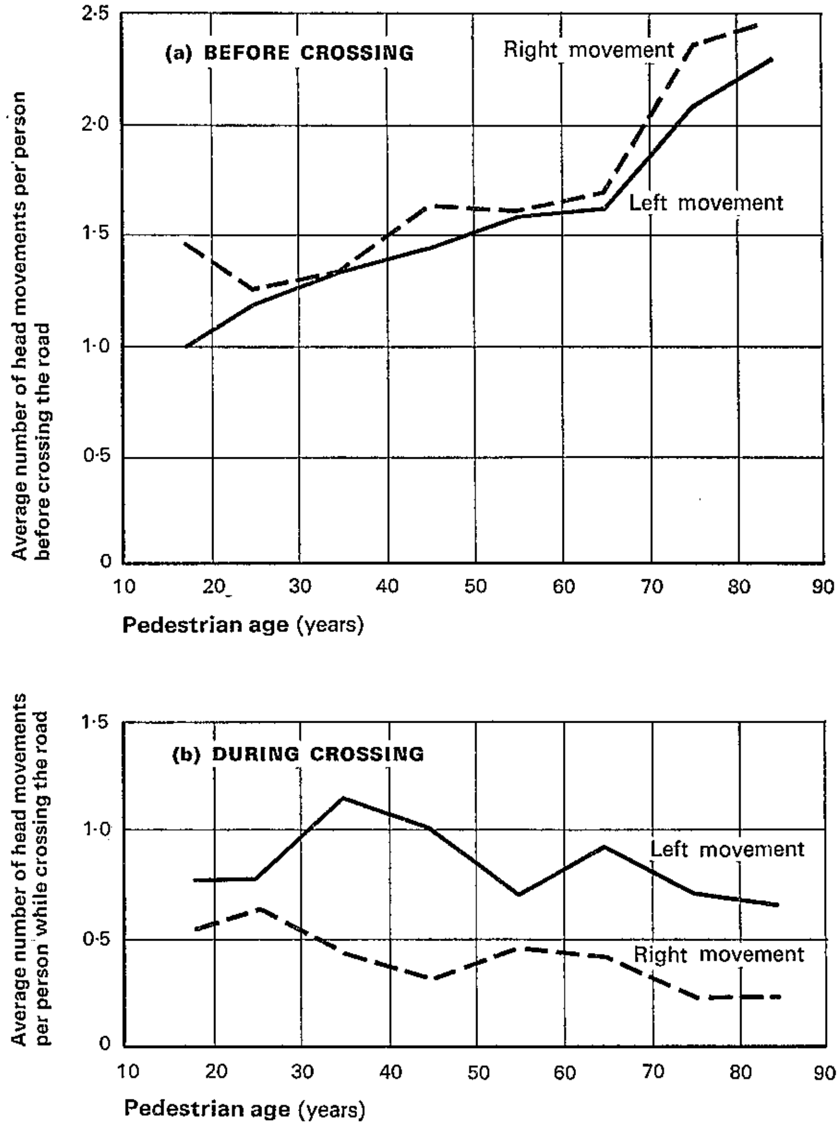
Studies at one junction showed that:

1. Two independent teams of observers gave very similar classification and location of conflicts suggesting that the method has some degree of reliability.
2. The age of drivers, known to be a factor related to certain junction accidents (see *Road Research 1970,*[6] p. 49), can be shown to affect behaviour. The manoeuvres of the elderly drivers differed from those of the younger drivers, greater delays and longer manoeuvre times being the usual differences noted. For drivers emerging from the minor road there is some evidence, not however statistically significant due to the sample size, that there is a higher conflict rate for the elderly drivers than for the younger ones.

3.3.4 Driver behaviour—safe and unsafe drivers

The research previously reported (see *Road Research 1968,*[38] p. 103), into the driving behaviour of drivers convicted of careless driving and drivers not so convicted has been continued. This work involved the development of a method of systematic observation of driver behaviour which could then be used to obtain a meaningful comparison of behaviour from

Fig. 39
Pedestrian head movements (a) before and (b) during crossing the road (including head movements made while walking before crossing)



driver to driver. The tests completed to date on a total of 540 drivers have now been analysed and a report published.[43] It was shown that the subject data for the two groups were similar except that there was a higher proportion of drivers in the 46–50-year-old age range in the convicted group and this group also had a higher proportion driving more than 25000 miles per year.

As a group, the convicted drivers stated they had been involved in more than twice the number of accidents admitted to by the non-convicted group.

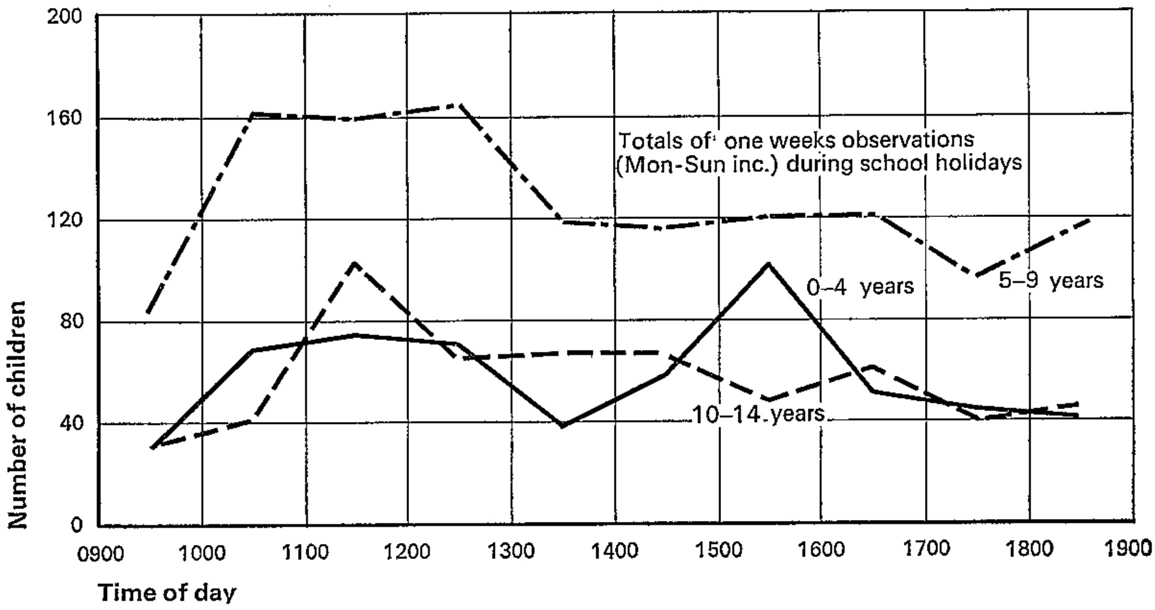
As regards driving behaviour, the convicted group used their rear-view mirrors less than the non-convicted group, gave fewer signals, showed more extremes of overtaking behaviour, drove at an average higher speed in the de-restricted zones, showed more lapses, carried out more unnecessary manoeuvres and took more risks.

When the drivers were classified into four sub-groups, each of which showed a characteristic pattern of driving behaviour, corresponding sub-groups in the convicted and non-convicted groups showed very few significant differences in the value of drive indices. The characteristic patterns of driving behaviour of the four sub-groups within both the convicted and non-convicted groups showed many differences.

In the group of drivers convicted of careless driving 39 per cent were assessed as showing safe behaviour when on the test route, 9 per cent were injudicious, 22 per cent dissociated active and 30 per cent dissociated passive. In the non-convicted group respective percentages were 61, 12, 9 and 18.

Within the non-convicted group, drivers in the safe class had a lower number of accidents than the unsafe classes. Within the convicted group this was not so, possibly because the group was not from a random sample of drivers.

Fig. 40
Numbers of children in different age groups observed throughout the day on roads in a residential estate



These results imply consistency of observation and classification and the ability of the method of systematic observation of driver behaviour to show meaningful differences in driver behaviour between classes of drivers.

3.3.5 Driver behaviour, personality and performance

Research has been carried out in an attempt to discover and delineate some of the main elements of driver behaviour, personality trends and performance test results that differentiate between 'safe' and 'non-safe'.

In a pilot study 20 drivers drove around a test route and were classified into four classes: S—safe, I—injudicious, DA—dissociated active, and DP—dissociated passive. Later these drivers took projective personality tests—consisting of questionnaire tests of intelligence and personality, and two performance tests—a two-hand co-ordination test, and a reaction test.

Only one significant difference was found among the classes of drivers on results of the psychological tests—on the E (Extroversion) Factor of the questionnaire personality test.

When the classification of drivers on the basis of projective personality test results was compared with that obtained from the systematic observation of driver behaviour, there was no statistically significant agreement.

Further data involving 150 drivers are being analysed.

3.3.6 International study of overtaking behaviour

The International Drivers Behaviour Research Association (IDBRA) sponsored by commercial undertakings of international repute has been set up with headquarters in Geneva to carry out co-operative studies of driver behaviour. The Laboratory is working with IDBRA which has based its British team at the Laboratory.

The first study to be carried out concerns overtaking behaviour, and three methods of investigation are being used:

1. A statistical method—data are to be collected on a sample of accidents involving overtaking to obtain information on the vehicles involved, the damage and injury resulting and the cause of the accidents. France, Germany, Holland, Switzerland, and Britain are involved in this method.
2. An observational method—driver behaviour will be studied under actual traffic conditions both generally (leading to a

classification of Safe and Non-safe drivers) and in particular, with emphasis on overtaking (leading to information on the elements of the overtaking manoeuvre —such as speed, level of potential danger, etc.). Germany, Italy, Sweden, and Britain are carrying out this work.

3. An experimental method—overtaking behaviour carried out on a track under controlled experimental conditions will be examined. Photographic or electronic equipment is to be used to obtain objective data on the drivers' time margins in overtaking with different speeds of the oncoming car and of the car to be overtaken. Countries involved in this research are Italy, Sweden, and Britain.

Pilot studies on all three methods have shown promising results and the first major study started in November 1971. This will consist of the examination of 1000 overtaking accidents for method (1) and the study of 100 subjects for methods (2) and (3), the same subjects undergoing both sets of tests.

3.4 Driver Aids and Abilities

3.4.1 Vehicle automation

Vehicle guidance. A simple electric steering actuator was fitted to a British Leyland Mini. This was found to allow satisfactory automatic guidance at speeds up to 100 km/h; following this an improved version including normal automotive power steering for torque amplification was installed in a Ford Cortina. The Cortina installation (Plate 14) has shown that no serious difficulties should be met in producing a design which would be acceptable to vehicle drivers. A coach has been purchased for conversion to automatic control; also a test 16 km length of vehicle guidance cable has been installed in the nearside lane of the M4 motorway near Reading to investigate installation techniques and cable characteristics.

Longitudinal control (speed and spacing). Both the Cortina and the Mini have been fitted with electro-vacuum brake and throttle actuators, using standard automotive components where possible. These actuators are controlled by electrical signals from a system which compares the vehicle's actual speed with a command speed signal supplied either from the driver's 'dial-a-speed' potentiometer or from inductive loops in the road. The system therefore allows remote control of speed, stopping, and starting, and also provides a useful aid for normal driving.

Research is continuing into automatic longitudinal control systems which will allow close following of one vehicle by another. Preliminary experiments have been carried out with two primary radar systems, but a study carried out at the Royal Radar Establishment, Malvern, for RRL suggests that any eventual full highway automation with high-speed short headway operation will require a 'co-operative' system in which all vehicles are fitted with active electronic equipment. At present the most promising co-operative longitudinal control system appears to be one where each vehicle measures its own position with respect to passive road markers (e.g. magnets) every 100–200 m and transmits its position, speed, acceleration, and lane to neighbouring vehicles by microwave link.

3.4.2 Aural communication

Communication with drivers. Research has continued into the possibility of communicating information to vehicle drivers aurally. The project is known as RITA (Road Information Transmitted Aurally) and studies to date have been concerned with the driver acceptance and technical feasibility aspects.

3.4.3 Driver acceptance

Some work has been carried out in London using volunteer drivers as subjects in order to gauge driver acceptance of such systems. Subjects were asked to navigate a route in Central London, 16 km in length with an average journey time of 55 minutes. Key locations such as main line railway stations, which were well signed, were used as destinations.

Subjects were required to navigate the route using: (1) visual signs, (2) visual signs and pre-recorded instructions relayed by a tape recorder, and (3) pre-recorded instructions only. In the last case the destinations were given fictitious names and the instructions prepared accordingly.

The main conclusion from these trials was that the majority of the drivers found the aural system very acceptable.

3.4.4 Technical feasibility

Investigations have continued at RRL on the technical aspects of RITA and a prototype inductive communication system has been developed using a transmitting loop buried in the research track. To gain further experience in this technique inductive loops were installed on the M4 motorway to evaluate loop characteristics under operational conditions.

3.4.5 Perceptual studies

The research carried out into perceptual problems has been mainly concerned with the detection of motion and speed. Research has continued into speed adaption and to the errors made in speed judgement using a simulator. With this device, a moving pattern, having the essential characteristics of a road, is presented to the subject. He is exposed for some minutes to a 'test speed', and is then asked to produce a speed which is, to him, half the test speed. Generally, subjects make considerable errors and over-estimate the required speed. It was found that when transverse lines (whose spacing decreased exponentially) were introduced on to the roadway, these speed errors were reduced in a useful direction. Subjects then produced a speed which appeared to them to be half the test speed, but which in fact was less than half its value. This speed reducing effect has fairly clear use on roads where traffic tends to approach junctions too rapidly.

A full-scale trial was carried out on the end of the A1M near Stevenage and in this the exponential line pattern was painted across the whole carriageway shortly before the terminal roundabout. A similar experiment was also conducted at a site on the M8 in Scotland. The results of the Stevenage experiment show that during the hours of daylight the pattern produced a 10·3 per cent reduction in speed for all vehicles. During the hours of darkness this figure rose to around 19 per cent. Data from the M8 site has not yet been analysed but the indications are similar to those at Stevenage. The value of these patterns is bound to be their ultimate success in reducing accidents at these sites. This of course is long term and will not be known for some time. In the meantime a number of other sites throughout the country are being treated with similar patterns. While no measurements have been taken under conditions of reduced visibility, reports from the public and local authorities indicate that the patterns are highly effective in fog. The majority of comments from members of the public have also been encouraging.

The other main field of research is into the factors underlying the perception of motion. A number of road accidents occur at junctions or in overtaking situations, possibly due to an inability on the part of the driver to perceive accurately the motion and speed of an oncoming vehicle. Apparatus has been constructed which will allow laboratory studies to be made of people's abilities in this respect. It will allow measurements of motion sensitivity with different visual frames of reference, like varying contrast and brightness. It is planned to use initially two groups of drivers, i.e. some who have had no accidents, and some who were involved in accidents whose primary cause could have been a lower than average perception of motion. The effect of the driver's age on his perceptual abilities will also be studied.

3.4.6 Night visibility

The 1969 national accident statistics contained street lighting information for the first time. Analysis of the figures revealed that three-quarters of all night accidents in 1969 occurred on lit roads, and that the majority of these (88 per cent) were on roads restricted to 30 mph.

Using traffic flow data, the relative accident rates for different light conditions have been estimated (Table 13).

This shows that the overall night accident rate is currently 1·3 times the day rate and that the highest rate occurs at dawn. The monthly figures show the highest rates to be when dawn coincides with peak travel times.

Table 13: Accidents in different light conditions and rates per veh/km, 1969

Light condition (defined by hour of day)	Accidents		Traffic flow 10^9 veh/km	Accident rate	
	Number	Per cent		Per 10^6 veh/km	Relative to daylight
Dark	62 636	24·1	38·1	1·64	1·33
Dawn	7 215	2·8	3·9	1·85	1·50
Dusk	14 010	5·4	11·0	1·27	1·03
Daylight	172 621	66·3	140·2	1·23	1·00
Total	260 647*	100·0	193·2	1·35	—

*Including accidents in which the police report of the light condition conflicted with the hour of day.

The effects of darkness combined with other potentially dangerous conditions, such as wet and icy roads, have also been examined.

In the early months of 1971 a random sample of 2000 drivers throughout the country was interviewed for the Laboratory on behaviour and attitudes concerning night driving. The analysis of the results is proceeding and it is hoped that a full report will be published next year.

Work on the automatic dimming headlight (dim-dip) for use in lit streets has now established the optimum rates for dimming and brightening. The system was described at the quadrennial Commission Internationale de l'Eclairage (CIE) meeting in September and accepted as a valuable contribution to the problems of vehicle lighting in lit streets. Plans for a large-scale trial in a suitable urban area are now being considered.

Glare-free headlight systems continue to be studied, with the search for a viable alternative to polarized light being concentrated on a headlight with a variable beam pattern. Current work involves assessing opto-electronic shutters and a research contract has been placed for the automatic recording of relative headlamp positions and intensities during meeting situations.

In public lighting, national and international co-operation has continued. Laboratory experience on the reflection characteristics of dry road surfaces has helped in the revision of parts of British Standards Code of Practice CP 1004.[44] The Laboratory is also taking part, through the National Illumination Committee and the CIE, in discussions and experiments relating to the international recommendations for street lighting embodied in CIE document 12.[45]

The Laboratory's street lighting model has been used in the subjective appraisal of new types of installation, such as uni-directional and catenary.

The performance of two lighting installations incorporating breakaway columns (on the A1 and the A4) is being kept under review.

Research has started into driver performance in the dark. The aim of the work is to find how some of the more common driver judgements, based on visual information, are affected by luminance level and luminance pattern. Initially suitable driver tasks and simple measures of performance are being investigated. Some studies at low luminance levels have been made on the research track.

3.4.7 Head-up display instruments (HUD)

Research into displays has been concentrated on the investigation of the way in which instruments are viewed during driving. This was done primarily to compare viewing times with those of conventionally placed (dashboard) instruments. The viewing time is defined as the time taken to change from looking at the road ahead to read an instrument, either dashboard or head-up display, and to look at the road ahead once more.

Measurements available so far are of the time to view dashboard instruments. Apart from purposes of comparison these measurements are of some interest in that they indicate the time that concentration needs to be removed from the primary driving task when an instrument needs to be read. The average viewing time was found to be in the region of 1·5 seconds. These measurements were taken under ideal driving conditions, i.e. on a research track with no other vehicles present. They therefore, probably represent the best possible viewing times. Measurements of comparable viewing times for head-up display instruments are not yet available.

As reported previously in *Road Research 1967*,[34] p. 86 and *Road Research 1970*,[6] p. 69, two head-up display instruments have been developed to the point where they could be demonstrated as feasible working systems. These are the head-up display Speedometer and the Station Keeping Indicator. However, if they are to be considered as realistic alternatives to existing vehicle instruments, their cost, reliability and technical simplicity needs to be carefully considered. This is being done on behalf of the Laboratory by Smiths Industries Ltd. It is intended that final designs of engineered pre-production prototypes will be available by mid-1972. Interesting points have already arisen from the work to date. The problem from the head-up display point of view is the windscreen. In neither overall form nor individual screen tolerances are present-day curved windscreens good enough to produce the high quality relatively distortion-free images which have been obtained from flat reflectors (either separate plates or flat windscreens) used in Laboratory demonstration prototypes. Work is in hand to determine what windscreen curvatures would be acceptable and to arrive at the display forms best suited to optical systems which have residual distortions.

4.1 Pavement Design Section

4.1.1 Full-scale road studies

Concrete pavements. The decision was taken several years ago to omit expansion joints in concrete roads constructed between 21 April and 21 October. This decision was based on early evidence from the Tuxford by-pass[46] constructed in 1967 which includes experimental sections 300 m and 1200 m in length laid without expansion joints. Compressive stresses have been measured continuously during the summer months and in these sections to date the maximum compressive stress measured has been 6·7 MN/m^2. A stress several times this magnitude would be required to cause buckling, and the results confirm that the risk of such failures is very small.

Detailed observations were made during the year on a number of plain concrete pavements recently laid with warping joints substituted for some of the sliding contraction joints. Early cracking (within 24–48 hours) was observed on several contracts, largely confined to days in which relatively high day temperatures were followed by cold nights. The extent to which this trouble can be overcome by ensuring free-sliding at the contraction joints and by providing a smoother finish to the sub-base is being investigated.

Flexible pavements. In connection with the preparation of papers for the Third International Conference on the Structural Design of Asphalt Pavements to be held in London in September 1972 a detailed analysis has been made of the results from the Alconbury Hill experiment constructed in 1957, and a first attempt has been made to examine the results in terms of elastic theory. Observations have been continued on the other full-scale experiments currently in progress.

To examine the economics of stage construction, in which the pavement is strengthened according to a pre-arranged plan to meet growing traffic requirements, proposals have been prepared for a full-scale experiment using various forms of flexible pavements. A site for the experiment is being sought.

4.1.2 Axle-load distribution studies

Development work on the capacitor-type weighing pad referred to in *Road Research 1968*,[38] p. 129 has continued. Although in principle satisfactory, trouble has been experienced with long-term durability due to failure of the bond between the perforated electrodes and the dielectric material. The pressing need for this type of equipment has led to the placing of a development contract with a firm specializing in this type of problem.

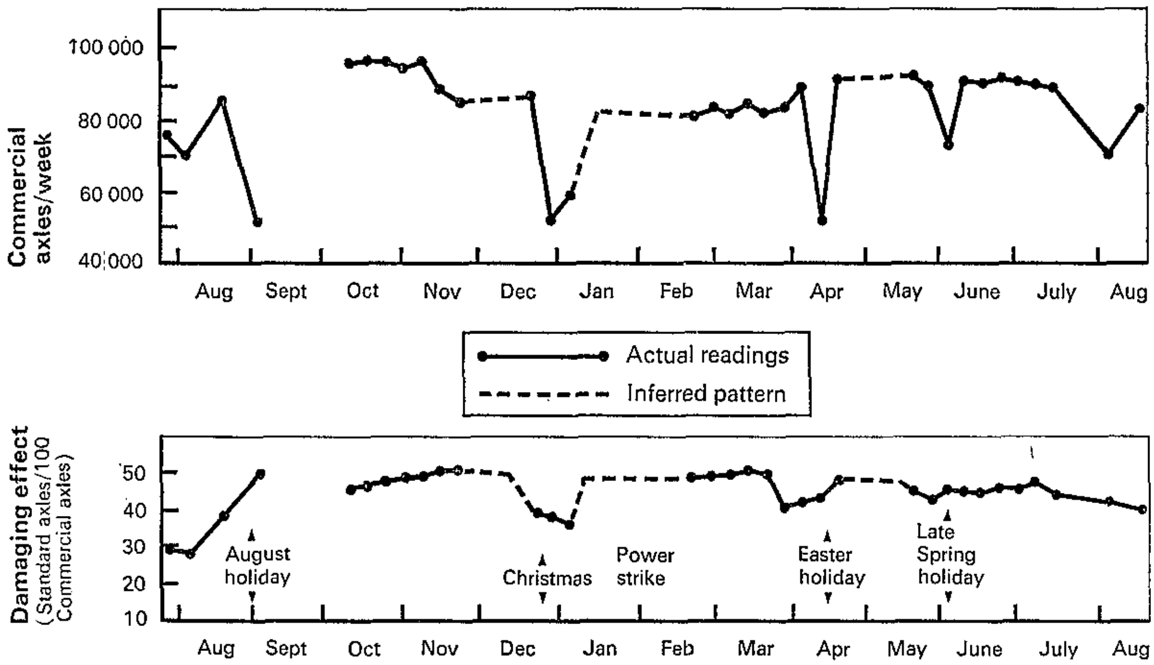
The damaging effect of the commercial traffic on different classes of road is meanwhile being studied using permanently installed weighbridges as described in *Road Research 1970*,[6] p. 74. Results over a period of one year for the south-bound nearside lane of the M1 motorway at Friars Wash are shown in Fig. 41. The upper diagram shows the number of commercial axles weighed each week and the lower diagram gives the equivalent number of standard 8200 kg axles per 100 commercial axles derived from the spectrum of axle loads observed using relative damaging factors derived from the AASHO Road Test.[47] In addition to the reduction of total commercial traffic which occurs during public holidays, the results show a marked reduction in the damaging effect of the traffic preceding the holiday. This probably results from empty or lightly-loaded vehicles returning to base, with only the more essential traffic running during the holiday period. The periods end-of-July/August and within two weeks of public holidays are clearly unreliable for studying the normal behaviour of commercial traffic.

4.1.3 Strengthening of existing pavements

The report of the Marshall Committee[48] has highlighted the importance of strengthening existing roads before foundation failure occurs under increasing traffic loads. Deflection studies started in 1955 to relate the transient deflection of a pavement under the passage of a known heavy wheel-load to the life-expectancy under road traffic have reached the stage where definite recommendations of the procedure as a maintenance tool can be made.[49] The recommendations will be incorporated in a publication in the Laboratory's Road Note series.

The exploitation of the Lacroix Deflectograph as a rapid means of assessing pavement deflections continues. As originally used

Fig. 41
Damaging factors and weekly axle totals over one year: M1, Friars Wash



the deflections measured in the nearside and offside wheel-tracks of the machine were recorded as traces on photographic or other light sensitive paper and these had to be measured manually. A digitizing unit has been fitted to one of the Laboratory's machines and the deflections are recorded automatically on punched tape for computer processing. Trials completed during the year show satisfactory agreement between the old and new methods of recording, and this will accelerate the data reading.

The machines have been used to prepare maintenance schedules for a number of major schemes. Assistance has been given to the DOE in setting up a unit for a pilot study in the Highways Directorate to obtain information on routine operation for SCRIM and the Deflectograph.

4.1.4 Research on underground pipelines
The objectives of this work are to refine current standards for the depth, bedding, and backfilling of pipelines, to reduce installation costs and at the same time to minimize the risk of failure in service. Pilot-scale tests are being carried out in the Laboratory grounds using test beds of various soil types. Instrumented lengths of pipeline are installed and the strains and deflection induced in the pipe during bedding, backfilling, and surface loading are measured.

Earth pressures round the pipes are also being recorded. Similar full-scale trials on normal pipelines are also being conducted. During the year such trials on a thin steel water pipe 1·8 m in diameter have been completed. The induced strains and deflections have been found to be surprisingly low and insufficient to require the normally specified lean concrete surround where pipeline passes under public roads. Proposals for similar trials in high road embankments have been prepared and it is hoped to conduct one of these during 1972 using a wide range of pipe materials.

Because of the range of variables involved, supporting theoretical work is considered essential to enable a measure of interpolation between experimental results. The finite element method is being applied to the problem and present indications are that there is an encouraging measure of agreement between computed and measured soil stresses and pipe deflections.

A new building to house the research team and to provide facilities for the instrumentation of pipes and small-scale loading trials should be completed in 1972.

4.2 Structural Properties Section

4.2.1 Research into structural design of pavements

The main objective of the Section is to develop for flexible pavements, a structural method of design that can adequately predict their behaviour under normal service conditions.

This requires the development of mathematical models representing the transient and long-term stress-strain-deflection behaviour of pavements and the testing of road materials, individual layers of the road, and complete pavement structures under appropriate conditions.

Assessment of mathematical models. The validity of ideal elasticity theory for predicting stresses and strains in pavements under vehicular loadings is being investigated on several instrumented full-scale pavements both at the Laboratory (see *Road Research* 1969,[5] p. 68) and on a trunk road.[50] Measured stress, strain, and deflection distributions have been compared with those computed[51, 52], by this theory, using laboratory and *in-situ* measurements of elastic modulus. The pavements concerned are all flexible, except for one specially simple design consisting of a concrete slab founded on a clay and a sand.

The results of the tests on the simple rigid pavement show reasonable agreement with the theoretical predictions, using wave propagation[53] and resonance tests on beam specimens to establish the modulus of the concrete, and wave propagation in association with CBR tests for the soil.

Results from two flexible pavements laid on the Road Machine (see *Road Research 1969,*[5] p. 68), have been analysed in some detail, one pavement (Section 1) has a rolled asphalt base, and the other (Section 3) a wet-mix base of the same thickness. The tests covered a range of vehicle speeds from 3·2 to 32 km/h, of static wheel loading from 3·2 Mg. to 6·4 Mg. and surface temperatures from about 10 °C to 45 °C. Elastic moduli for the soils and unbound base and sub-base were obtained by wave propagation, and for soil by CBR tests. Effective elastic moduli for the bituminous materials were deduced from measurements of the complex Young's modulus (see *Road Research 1970,*[6] p. 77) at the appropriate temperature, and by assuming an effective loading frequency given by the reciprocal of the duration of the vertical normal stress in the soil.

The theoretical results from Section 1 were in good agreement with measured values at low temperatures; deviations occurred at higher temperatures and were attributed partly to difficulties in assigning an effective modulus to the asphalts in this temperature range, and partly to non-linearity in the unbound base. Effects of such non-linearities were observed for the weaker Section 3 even at low temperatures.

Behaviour of road materials under repeated loading. Research is continuing on the resistance of typical road materials to repeated loading. Some of this work is being undertaken in extra-mural contracts at the Universities of Nottingham, Birmingham, and Surrey and some at the Laboratory in collaboration with the Refined Bitumen Association and the British Tar Industry Association.

New equipment is being obtained for testing soils and unbound granular materials under repeated triaxial loading, in which the stress histories of both confining pressure and deviator stress may be varied over wide limits. One of the difficulties of such tests is the accurate determination of vertical and lateral displacements of the test sample; possible techniques for doing this without introducing any constraints on the material under test have been investigated.

Fatigue tests on pavement quality concrete and on lean concrete have confirmed the dependence of fatigue strength on moisture condition and have shown increases in fatigue performance with age for specimens up to two years old. Aggregate type has also been shown to have an effect both on fatigue performance and on mode of failure.

The potentialities of fibre-reinforced concretes have been reviewed for possible applications to highway structures such as pavement slabs, bridge components, and tunnel linings and a research programme has been drawn up in conjunction with the Building Research Station to study the properties of such materials.

Studies of the fatigue performance and cumulative deformation of bitumen-bound and tar-bound materials have continued. The effects of the time history of the applied loading over a range of loading frequencies and temperatures in uniaxial fatigue tests show that the shape of the waveform of the applied loading is relatively unimportant under controlled stress conditions compared with the very marked effect of rest periods between loading pulses. The effects of temperature loading frequency and stress on the cumulative deformation and moduli of these materials are being studied under repeated multiaxial stresses; initial results show that temperature is the most important of these parameters.

Repeated loading of pavements. Experiments with the No. 3 Road Machine (see *Road Research 1969*,[5] p. 68) to examine the relative damaging effects of wheel loads and high temperatures have continued for the pavement with a crushed stone base, using a wheel load of 6·8 Mg. Results obtained so far have confirmed the effects of surface temperature which were obtained with a 5 Mg. (static) wheel load. Further analysis of the results is yielding quantitative information which will be compared with that from similar pavements in the RRL full-scale road experiments. Similar experiments are planned for the pavement with a rolled asphalt base. Modifications have been made to the Road Machine to improve its efficiency as an accelerated method of testing pavements.

Structural analysis of the behaviour of experimental sections in the Road Machine and in full-scale pavement design experiments requires information on the mechanical and physical properties of the construction materials, at various stages of their service lives. Work is in hand to develop acceptable means of retrieving samples of pavement materials and soils so that these may be subjected to laboratory tests to measure their dynamic properties and their resistance to repeated loading at selected stages of their service life.

Effect of water-table level on performance of a bituminous pavement. An experimental rig is being built to investigate how variation of the depth of the water-table in the subgrade affects the dynamic stresses, strains, and deflections developed in a typical bituminous road by moving vehicles. A concrete lined tank 20 m long by 10 m wide by 2 m deep with a non-rigid waterproof base, has been constructed in the Laboratory grounds. Instruments for measuring stresses, strains, and displacements in the structure have been prepared together with automatic equipment for recording pore-water pressures. Brick earth, placed and compacted in thin layers, provides a reasonably uniform and well compacted subgrade on which the road structure will be built. Measurements will begin as soon as the soil water conditions stabilize.

4.2.2 Drainage studies

Pervious surfacings to reduce splash and spray. Splash and spray from vehicles travelling at high speeds on wet roads are reduced by pervious surfacings (bitumen macadam) laid on the normal impervious surface. (See *Road Research 1968*,[38] p. 132). To check their resistance to compaction by traffic, six experimental sections were laid on Trunk Road A45 at Stonebridge in collaboration with the Warwickshire County Council. After 16 months of very heavy commercial traffic all are still performing satisfactorily and observations of performance are providing estimates of their working life.

A pervious surfacing has been laid on Trunk Road A40 at Northolt in collaboration with the London Borough of Hillingdon. To obtain data needed for design, measurements are being made of the water flowing through the surface, the time to saturate the layer and the interval during which water continues to flow after rain has ceased.

Sub-base drainage experiment. An experiment has been built to measure the drainage occurring in sub-base material (crushed limestone laid at different slopes) and to obtain relations between drainage, permeability, pore space and time. Pore pressure measuring equipment recording on punched tape has been constructed and installed, and manometres, flow-metres, and artificial rain apparatus have been commissioned.

4.2.3 Surface irregularity

Bump integrator. The recommendation by the Committee on Highway Maintenance that the Bump Integrator should be used for the routine assessment of riding quality has led to a considerable interest in this equipment. A questionnaire survey showed that there were 15 Bump Integrators in Great Britain, including three owned by the RRL, but that even where regular measurements were made authorities seldom used the results to help determine when resurfacing or repair was needed. Research into better methods of assessing surface quality is continuing.

Research into ride. Experiments comparing subjective assessments of riding comfort in vehicles with objective measurements of acceleration input at the seat-person interface have continued over a range of road surfaces. A research contract has been placed with the University of Birmingham for the measurement of vibration transfer characteristics of typical present-day vehicles including some of those used in these riding comfort experiments.

Profilometry. Theoretical comparisons are being made between two possible forms of absolute longitudinal profilometer. Laboratory development of a contactless sensor for use in profilometers has continued and the present prototype sensor has been designed to measure its height above the road within the range 300 to 325 mm with a resolution of 0·25 mm. When used in a vehicle travelling at 96 km/h it will be capable of making height measurements at intervals of 5 mm along the road.

4.3 Bridges Design Section

4.3.1 Fatigue

Tests on the fatigue rig for simulating traffic loadings on bridge decks have shown that, with the twin actuator loading system, the local stresses in a steel deck panel due to a rolling wheel can be satisfactorily reproduced at a selected gauge point. A loading rate of 10 Hz at 100 kN can be achieved. Fatigue tests on a deck panel with trapezoidal stiffeners will be made to confirm results which have been obtained on small specimens under a research contract at the Welding Institute.

Recordings of strains in various portions on the prototype deck panels installed at Denham A40 (see *Road Research 1963*[54], p. 124) have been made for a period of one week. The results have been analysed in terms of various methods of classification, i.e. strain peaks, strain ranges, etc., and demonstrate clearly the considerable reduction in strain values recorded on the panel with 9·5 mm resin based surfacings.

4.3.2 Steel box girders—structural analysis and testing

During 1971 the Committee on Steel Box Girder Bridges, formed with Dr A. W. Merrison as chairman, following the collapse during construction of the Milford Haven and Yarra Bridges, issued an interim report[55] and commissioned several items of urgent research at various establishments. In order to co-ordinate the results of this short-term research with the necessary longer-term research on this subject a Working Group on Research into Steel Box Girder Bridges has been formed with joint chairmen from the Laboratory and Bridges Engineering Section, DOE, and including appropriate members from outside the Department.

Meanwhile various aspects of the Laboratory's research on bridges have been modified to place more emphasis on the structural behaviour of steel box girders. Preparations for measuring strains during reconstruction of the Milford Haven Bridge are mentioned in Section 4.4.1. A start has also been made on:

1. Analytical studies.
2. Tests on small-scale models to verify the analytical methods used in (1).
3. Test on large-scale models (half to full size) to study the whole range of behaviour up to collapse under realistic conditions including the imperfections arising from fabrication construction assembly procedures.

The analytical studies are concerned with the buckling and collapse of welded stiffened plates under various boundary forces and with an investigation into how component behaviour can be used to design stiffened box girders against collapse. For the analysis of inelastic plate buckling, a computer program for elastoplastic bending of plates based on the method of finite differences has been modified to deal with membrane forces and large deflections. However, the program can be applied only to square plates. A more versatile program for inelastic buckling based on the finite element technique is being developed. Solutions will be checked against available test results before further development to study the effects of stiffeners.

A program for the linear elastic analysis of box girders has been developed[56] and is being used to study the interaction of various plate components (flanges, webs, and diaphragms) in the elastic phase. For the more complex problem of interaction at collapse, the initial approach will be to analyse the girder elastically to determine boundary forces on various critical components, and then to analyse the isolated components individually to collapse. This situation will be clarified as test results become available.

A test rig has been prepared for test on small-scale models to verify the theory on which the analysis is based. Model box girders having a span of up to 4 m can be used and the first series of tests on unstiffened boxes has been completed.

Designs have been completed for a series of tests on models of approximately half full size with loading to simulate the shear and flexure in the support region. The instrumentation being provided will measure general and local deformation and the distribution of strain.

4.3.3 Limit state and optimized design

For the study of limit state design of reinforced concrete slabs, a program of elastoplastic analysis has been developed,[57] using Johansen's yield criterion. Various slabs have been analysed from zero load to collapse in order to study the validity of simple design methods in predicting the occurrence of various limit states. The distribution of bending moments at collapse has been studied in order to provide the information needed for determining the arrangement of the reinforcement (Fig. 42).

A program for the optimized design of bridge components has been developed and applied to the minimum cost design of plate girders with intermediate stiffeners. It is difficult at this stage to assess the economy achieved since an 'average design' would have to be defined for comparison. However, it has been found that the technique will produce correct results even when the input to the computer is based on an initial design not complying with the Codes of Practice. The application of the technique to limit state designs is being considered.

4.3.4 Concrete bridge decks

The limit state behaviour of precast prestressed concrete beams is being studied under controlled conditions in the Laboratory. Static and repetitive loading tests have been made to examine the initiation and development of cracking and its effect on the distribution of stress in the beam. The tests are also providing some information on whether the loading history has any effect on the mode of collapse, particularly with regard to the effects of cracking on fatigue of the prestressing tendons. This work is continuing.

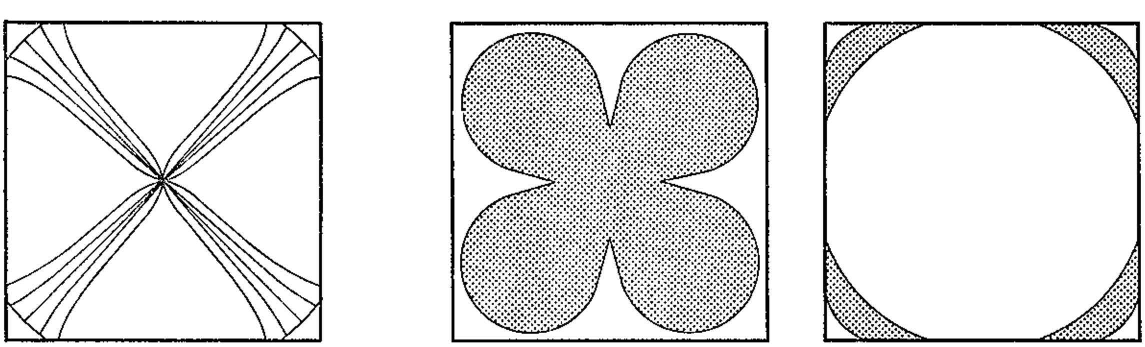
The work so far carried out on the use of lightweight aggregate concrete for bridge decks has included a study of the behaviour of a bridge deck, repetitive loadings tests to study the development of flexural cracking and measurement of loss of prestress. This work has shown little difference between the behaviour of lightweight aggregate concrete, and that of normal concrete of similar strength, provided that account is taken of the differences in elastic properties and durability requirements.

4.3.5 Waterproofing of concrete bridge decks

Since this work was last reported (see *Road Research 1969*,[5] p. 82), several new materials have become available and their use for waterproofing bridge decks has been evaluated. These materials include developments of the epoxy and polyurethane based preparations and modified bituminous materials. There is some progress in the industry towards the development, against the Laboratory's criteria, of materials which are more robust and more tolerant of adverse site conditions during application.[58]

The three major problems now are blistering, drainage within the surfacing, and stability of the surfacing. Blistering occurs when the applied waterproofing is left exposed for several days while it is subjected to a large diurnal temperature variation. The most satisfactory method of prevention is to complete the bituminous surfacing as quickly as possible. Where this is found to be impracticable a venting layer may be used beneath the waterproofing. Account should be taken, however, of the

Fig. 42
Clamped square slab: Mechanism and Ultimate-Moment Zones at collapse



COLLAPSE MECHANISM — POSITIVE MOMENT — NEGATIVE MOMENT resulting reduction in bond between the surfacing and the deck in situations where large horizontal shear forces are produced such as on steep gradients and at road junctions.

The problem of preventing an accumulation of water on the waterproofing membrane at points where joints, kerbs, etc., impede horizontal flow is being dealt with in some countries by providing inlets to gullies or perforated horizontal drainage tubes laid within the surfacing material. Where conditions make subdrainage necessary, these methods offer a solution and experience in this country would be useful.

Cases of surfacing deformation have been investigated. As yet there are insufficient data for the cause of this deformation to be established, but certain aspects appear significant. In all instances surfacing deformation has been associated with one or more of the following: lack of bond at the waterproofing, high braking forces, steep gradients, an excessively thick protective layer, thin surfacing construction or a very lively structure with respect to vibration. It is proposed to observe the structures where remedial work has been carried out in order to determine more accurately the cause of these failures and to establish whether any recommendations are needed.

4.3.6 Traffic induced vibrations

A comprehensive survey[59] has been made of the generation and transmission of vibrations from road vehicles and their effects on people and buildings. When the smoothness of the road surface conforms with the Specification for Road and Bridge Works, 1969, vehicles do not generate vibrations large enough to be perceived by people or cause 'architectural damage' (such as cracking of plaster) in normal dwelling-houses close to the road. But when the road surface begins to deteriorate, vibrations are perceived by people and there is a risk of damage to buildings (Table 14).

Preliminary tests on the dynamic loading from vehicles of different weights have shown that vibrations and impact loads result from the effect of individual axles rather than vehicles as a whole. These effects are being investigated further using a computer program and full-scale tests.

The equipment and techniques developed for measuring the dynamic properties of bridges have been used to investigate the effect of structural changes and surfacing on highway and foot bridges. Tests on a cantilever and suspended span footbridge have shown the significance of the handrail system in coupling the suspended spans to the cantilever sections. The natural frequency was increased by 30 per cent although damping was not affected. Further tests have been made to investigate the contribution of surfacing materials to damping. Full-scale tests are being made on selected types of bridges to determine the structural parameters which contribute most to liveliness. Bridges have been inspected where action has had to be taken to reduce vibrations to acceptable levels for pedestrians.

4.4 Bridges Behaviour Section

4.4.1 Field experiments

Over the year there has been an expansion of the field trials group studying the loads on, and the behaviour of bridges, and relating this behaviour to methods of analysis and design. Field studies are usually limited to investigations which can only be done on the full scale or which are less expensive to do in this way. The necessary data logging equipment for strain and temperature measurements has been acquired and performance trials initiated. Development of gauges and gauging techniques is in progress. A recording water level gauge has been developed for the measurement of transverse bending deflections. Under laboratory conditions it has a precision of ±0·05 mm, with tubes up to 40 m long. It can

Table 14: Summary of the effect of vibrations on people and buildings

Peak particle velocity (mm/s)	Effect of ground-borne vibrations on:	
	People	Normal buildings
0·15–0·3	Threshold of perception	No damage of any type
2·5	Threshold of annoyance	No damage of any type
5*	Vibrations annoying	Threshold of 'architectural damage'
10–15	Vibrations unpleasant	Risk of minor structural damage

*Vibrations of this magnitude have occurred close to roads having surface irregularities of about 20 mm in size.

be used to measure differences in level between points which are up to 40 m apart. Field trials are being carried out in a multicellular concrete bridge under construction over the Thames at Marlow.

Vibrating wire strain gauges have been installed on each side of the longitudinal interface between pre-cast units and *in-situ* concrete of a prestressed bridge over the M4 at Shinfield near Reading. Results show that there was efficient transfer of load across the interface when the prestressing was applied, as shown by the small strain differential. The effect of traffic on the strain difference at the interface will be monitored for a period of at least two years.

Work has started on instrumenting the Milford Haven Bridge in an attempt to monitor the stresses in the diaphragm, web and flanges of the box girder over one of the piers during reconstruction.

4.4.2 Temperature effects

One of the aims of the work on the thermal behaviour of bridges is to provide a correlation between bridge temperature and ambient shade temperature. An approximate relationship between these two temperatures during extreme environmental conditions has been reported previously.[60] Present work is directed towards developing a more general method for estimating the bridge temperature at any time from the information on shade temperature issued by the Meteorological Office. This method is being verified against data obtained from five concrete bridges of various types and it is proposed to extend it to cover steel on composite construction.

Data have also been obtained on temperature distributions, temperature gradients, movements, and coefficients of thermal expansion for the various types of structures.

4.4.3 Bridge bearings

The purpose of the current programme of research on bridge bearings is to assess the nature and magnitude of the forces transmitted by the bearing between the deck and its supporting structure. Laboratory and full-scale studies of the performance of PTFE-based sliding bearing materials have continued.[61] An experimental system has been developed to enable the frictional forces generated in any type of bridge bearing to be monitored over a long period, without the need for modification of the bearing itself. The system has been installed in the Adur Bridge (A27) to monitor the performance of one type of PTFE sliding bearing. On the same site an investigation of the frictional characteristics of high tensile steel roller bearings has recently commenced, using vibrating wire strain gauges embedded in the support columns to monitor bending strains due to friction in the bearings.

The investigation of the static and dynamic characteristics of laminated rubber bearings has included the analysis of data obtained from a study of the bearing reactions on a skew slab bridge under abnormal loads. The deflection of the rubber bearings under load was measured and related to load/deflection calibrations obtained by laboratory tests. Maximum bearing reactions were found to occur at the obtuse corner at the expansion end of the structure but no symmetry between fixed end and expansion end reactions was observed. There were marked differences between the measured reactions and the theoretical predictions, and it was concluded that the compression characteristics of the bearings were modified by slipping at the interfaces with deck slab and abutment. Further detailed investigations are required to produce data to check current theoretical and model analysis of the behaviour of skew slab structures.

4.4.4 High strength friction grip bolted connections

The effect of corrosion on the strength of friction-grip bolted joints has been studied by testing specimens exposed to an aggressive marine environment at Shoreham, Sussex. The contact surfaces of a double lap joint were first grit blasted: some specimens were then bolted together without further treatment, whilst others had their contact surfaces sprayed with zinc and aluminium. Periodically, specimens are tested to measure changes in the bolt load friction coefficient (slip factor) across the joint.

Grit blasted specimens have now been weathered for periods of up to 22 months. Specimens which weathered the winter of 1969 have shown an increase in bolt tension of up to 10 kN per bolt, whilst those exposed from April 1970 onwards have generally tended to lose bolt tension by approximately the same amount. The reasons for this are not fully understood, but it is possible that the winter of 1969 had a higher frequency of strong winds, which would have increased the amount of seawater spray to which the specimens were subjected. The increase or decrease in bolt tension has not produced any significant change in the values of slip factor obtained from tests after 6 and 12 months exposure: however, the mode of failure has altered. Freshly prepared joints slip smoothly with increase in load for movements of approximately 0·1 mm before complete slip. In corroded specimens, however, the onset of complete slip is sudden.

Zinc metal sprayed specimens have been exposed for just over one year. Tests after 6 and 12 months have given values of slip factor marginally higher than for fresh specimens, although the tendency has been for the bolt tension to decrease by approximately 10 kN per bolt. The mode of failure has not altered. Some aluminium metal sprayed specimens have been prepared but they have only been exposed for two months and have yet to be tested.

4.4.5 Weather surveillance on motorways

To combat the adverse effects of the accumulation of ice and snow on roads preventative measures should be undertaken before the occurrences. This means that the appropriate authorities must be given some advanced warning in order to mobilize maintenance crews.

The usual source of adverse weather warnings are the Meteorological Office forecasters who are handicapped in that they have no accurate, up to the minute knowledge of actual road conditions. To overcome this disadvantage, apparatus has been developed to give warning that ice formation is imminent from sensors installed in roads.[62] They cannot predict future trends, but they can assist the forecaster to give a more accurate prediction. The problem of relaying the road data to the forecaster would be largely overcome if the proposal to equip the motorway network with a computer controlled communication system is implemented. This will be able to interrogate weather sensors and send the data via a suitable link to the appropriate local Meteorological Office. To test how such a link is best established, sensors to measure road surface temperature, wetness and salinity, air temperature, wind speed and direction and rainfall will be installed by the Winter of 1972–73 at four sites on the M62 Trans-Pennine Motorway near Scammonden Dam and at two on the M4 near London Airport. Initially, the motorway computers will transmit the data to a small satellite computer at the Laboratory which will record the data for checking and when appropriate critical levels are reached transmit warnings and data to local forecasting offices and other selected interested authorities. If the trial is successful further sites will be installed and the motorway communication computers will be programmed to undertake all the necessary tasks to ensure that the proper authorities are alerted.

4.4.6 Wind effects

Some vehicles, particularly high sided vehicles and car-caravan combinations, suffer accidents through strong winds. On bridges, viaducts, and embankments the consequences of such accidents can be much more serious than if they occur on other sections of roads so there is a need for means to reduce the effects of strong winds at vulnerable spots. Fortunately, over much of the United Kingdom, the incidence of strong winds is not high which means that progress in full-scale investigations into methods of wind modification is slow. To accelerate the work a contract has been placed with the National Physical Laboratory to carry out model tests in wind tunnels to determine the efficiency of a variety of wind breaks on a number of typical bridge and viaduct configurations. The results of these tests are being reinforced by full-scale measurements when suitable conditions occur.

4.4.7 The corrosion prevention of structural steel works of bridges

Full-scale painting trials of newer protective systems were carried out during the period 1965–68.[63] However, one of the major problems in deciding which paint system to recommend for new steel bridge works is lack of knowledge of climatological and air pollution factors at the site. The British Standard Code of Practice CP2008,[64] has classified these various environments into five categories: rural, industrial, chemical, coastal, and marine. A classification of this type, is, however, purely descriptive and a much more specific classification of any particular site is necessary before a material or paint system can be recommended with confidence.

To resolve this problem, corrosion test sites have recently been established at six existing or proposed bridge sites covering a range of environmental conditions. The aim of the work is to establish that corrosion rates and contamination levels can be conveniently and usefully measured. These data would be used in making a choice of the most appropriate paint system. It might indicate that, for some sites, an unpainted low alloy or galvanized steel was acceptable, whereas, for very corrosive environments, steel was not appropriate.

Concurrent contract research at the Paint Research Station will assist the choice of paint primer for particular environments. From all of this information it should be possible to devise the preferred protective paint systems for a range of environments.

4.5 Tunnels Section

The investigations into tunnelling demand over the next two decades which led up to the decision to form the Tunnels Section within the Design Division at the Laboratory were described in *Road Research 1970*,[6] pp. 5–7. These investigations showed that there is likely to be a substantial increase in demand for road tunnels in the decade 1980–89 to satisfy the demands of motor traffic in cities and towns without detriment to amenities and living standards in these areas. Roads underground can create vital new space just where it is most needed, thus limiting urban sprawl. It was estimated that in that decade at least £200 million would be spent on roads in tunnels and there was strong likelihood that the figure would be considerably greater (see p. 10, Part One). Additionally there are sizeable demands over the next two decades for other transportation tunnels. It was concluded that such tunnelling demands warranted a considerable research effort both within the Laboratory and extra-murally in industry, universities and research organizations.

4.5.1 Research Committee on Tunnels

Because of the importance of the formative stages of the programme of research on tunnels the Director formed a Research Committee charged with advising specifically on this topic. Two meetings were held during the year. The terms of reference and membership of the committee are given on page 103.

4.5.2 Structural loading and ground properties

The aim of this research is to determine the loads imposed on tunnel linings and to develop and improve design methods; additionally settlements of buildings adjacent to tunnelling schemes must be minimized. There are considerable and crucial gaps in present knowledge of tunnel lining loading and behaviour, as has recently been experienced.[65, 66]

It is envisaged that the initial attack on these problems will be through full-scale measurements recording strains and pressures in tunnel linings and surrounding ground; settlements and soil movements would be monitored during and subsequent to tunnel construction. These primary data on actual tunnel behaviour collected as and when opportunity permits will be augmented by laboratory studies of relevant ground properties.

During the year preliminary tests on over-consolidated heavy clay and chalk samples have been undertaken and exploratory work has begun for the testing of model tunnels using the recently developed centrifuge technique; a specification has been drawn up for the finite-element programmes required for the theoretical analysis.

4.5.3 Construction operations and plant

Research on these topics is directed towards developing and improving existing tunnelling methods and the services such as ventilation needed in road tunnels. The emphasis is again on full-scale measurements under actual tunnelling conditions and preparations are in hand for trials with tunnelling machines in one of the weaker ground formations.

The Mining Department, University of Newcastle upon Tyne, has investigated as a research contract the cutting and other properties of Lower Chalk with the object of determining the most efficient shape and array of tools to use on a tunnelling machine working in this formation. Both picks and disc cutters are being studied. Plate 15 shows a pick being tested on a specimen of chalk in a modified shaping machine; the vertical, forward and sideway forces on the cutting tool are monitored continuously during the test and the amount of chalk excavated is measured. The work should be complete and the final report drafted early in 1972.

A review of methods currently in use to ventilate road tunnels has been completed. The study showed that there were wide differences in the standards of ventilation adopted and that there was a need to rationalize these. In the past, too, ventilation system had for the most part been designed for tunnels in subaqueous locations. With the change in emphasis to using tunnels in built-up areas there was a need to develop simpler and cheaper systems to exploit the virtually continuous access to the ground surface in such situations.

A study has been carried out of the cost of operating road tunnels in this country. The study showed that annual running costs between £10,000 and £15,000 per two-lane kilometre at 1970 prices can be expected for roads in tunnel without tolls, and with traffic control and breakdown services provided by local police forces and garages respectively. These costs discounted to present values represent some 5–10 per cent of the cost of the cheaper road tunnels built in good ground.

4.5.4 Traffic and layout

The objective of this research is to standardize geometrical requirements for road tunnels and examine the problems posed at junctions between road tunnels and between these and the road system at the surface.

Vehicle breakdowns and accidents could be a more serious difficulty below ground than at the surface. Data on the incidence and duration of breakdowns supplied by the Mersey Tunnel Joint Committee has been analysed. Additional information is being collected on the elevated section of the M4 at Brentford. Data on the height distribution and lateral spacing of vehicles have also been analysed. This information should enable benefits deriving from the provision of hard shoulders to be assessed and logical choices to be made in selecting height clearances and lane widths for road tunnels.

During the year, visits were made to Brussels and Rome to study underground road junctions in those cities with the assistance of the local authorities responsible. During the visits the operation of the junctions were studied in some detail and information collected on their design, construction, and operation.

5. CONSTRUCTION DIVISION

5.1 Earthworks and Foundations Section

5.1.1 Site investigation and soil properties

Preliminary sources of information for use in site investigations. Preliminary information on ground conditions is essential for sound route location and the early recognition of engineering difficulties, and later for the economical planning and effective interpretation of the full site investigation. Much information of this kind can be obtained at low cost and at an early date by consulting geological, soil, land use and hydrogeological maps and memoirs. Useful data may also be available from mine records and air photographs, and from a thorough site reconnaissance. The availability of these sources and the type of information obtainable from them has been reviewed.[67]

Among these sources of preliminary information are site investigation reports for other engineering works in the proposed construction area. A collection of such reports for motorways and trunk roads is available for inspection at the Laboratory. The collection is continually being added to as new surveys are completed and at present consists of over 200 reports in 550 volumes containing records of over 5900 boreholes. Although more specific data would eventually be required for detailed design work for a new road, these reports can give useful early information on the type and thickness of the different strata in an area, the depth of the water table, and general information on the geotechnical properties of the materials such as grading, plasticity, moisture content, strength and consolidation characteristics.

Application of the scanning electron microscope to the study of engineering soils. Although it was acquired primarily for other purposes, the opportunity has been taken to assess the applicability of the scanning electron microscope to the study of engineering soils. Previous applications in soil mechanics have been reviewed, and stereo-pairs of electron micrographs of a number of soils and soil constituents have been made. The applications are principally in the examination of particle orientation and inter-particle relations, and in the examination of the nature of the soil particles themselves. The work with the microscope showed that the instrument is particularly effective for studying sand and silt grains and for clay soils having relatively large clay particles.

Measurement of the residual shear strength of soil. When cuttings are made through over-consolidated fissured clays the shear strength along potential failure surfaces decreases with time from the peak value measured in conventional tests towards a lower limiting or residual value. This residual value also represents the available strength along slip surfaces formed by previous movements in any cohesive soil. Both shearbox and triaxial techniques have been examined for the measurement of the residual shear strength of clays. The study involved tests on specimens prepared from undisturbed and remoulded samples and the procedures used were in general similar to those employed for standard consolidated drained tests.

In the shearbox test, the specimen is sheared to a large strain by repeated forward and reverse travel of the box. This test can be carried out directly on intact specimens or on specimens containing a natural or artificially produced shear surface. The triaxial test can only be carried out on specimens containing a natural or artificial shear plane inclined at an angle of approximately $\left(45 + \frac{\phi'}{2}\right)$ degrees to the specimen diameter. In the triaxial test the rubber membrane and paper filter drain imposes a restraint on the specimen and a correction has to be made to the measured stresses. A detailed investigation has been carried out to determine these corrections, using a perspex cylinder containing an inclined cut to simulate a slip surface. The apparatus used at the Laboratory for the measurement of residual strength has been modified to enable automatic control and collection of data to be achieved.

5.1.2 Settlement and stability of earthworks on soft foundations

Settlement and stability investigation at Avonmouth. The construction of the M5 motorway, from the river Avon, south-east of Avonmouth, to link up with the existing motorway at Cribb's Causeway involves considerable lengths of embankment on compressible soils. Some of the embankments, which rise to about 9 m at minor road crossings and at the Avonmouth interchange, introduced serious settlement and stability problems. To provide information to assist in the design and construction of these embankments, a section of the high embankment at the Avonmouth interchange was constructed as a trial in advance of the main contract to enable a full-scale investigation[68] to be carried out by the Laboratory.

The aim of the investigation was to establish whether embankments of the heights required at the interchange could be built without shear failure, and whether the settlement of these embankments subsequent to the completion of construction would result in unacceptable deformation of the road surface. The information was also expected to be valuable in the design and construction of embankments on other sections of the motorway on the alluvial plain.

The records of settlement obtained during and after construction indicated that although the magnitude of the ultimate settlement was likely to be in close agreement with the predicted value, settlement in the field occurred much more rapidly than was estimated using the data from laboratory consolidation tests (see *Road Research 1965–66*,[69] p. 86). The use of the soil parameters determined from laboratory tests clearly produced significant underestimates of the rate of settlement and porewater pressure dissipation. A more satisfactory settlement prediction was obtained (Fig. 43) using the results of *in-situ* permeability tests (see *Road Research 1970*,[6] p. 92), together with a method of settlement analysis which employs more realistic assumptions than those of the conventional theory.

Settlement analysis of multi-layered soils. A situation which often occurs in major road schemes is the requirement to construct embankments on compressible alluvium consisting of several layers of soil with different properties. Frequently, because the embankment is wide in relation to the depth of compressible strata, it is possible to analyse the settlement of such embankments on the basis of Terzaghi's one-dimensional theory of consolidation. However, as the theory involves an assumption that the soil is homogenous, strictly it cannot be employed for analysing settlement with stratified deposits. Under such conditions, use has to be made of a multi-layer theory of consolidation which takes account of the variation in soil properties. One convenient method which can be used involves the replacement of the differential equation of consolidation by finite-difference approximations. As the method is basically a numerical procedure it is well-suited for use with a digital computer. A computer program has therefore been developed at the Laboratory for analysing the one-dimensional consolidation of stratified soils. The program permits the analysis of multilayered soils where up to 20 layers with different properties are present and further permits the soil parameters to vary during the consolidation process. Instantaneous and multi-stage forms of construction loading can also be treated by the program.

The accuracy of the solutions obtained using the computer program have been confirmed by comparison with available solutions to several consolidation problems (see Fig. 44).

The program was used for analysing the settlement and dissipation of porewater pressure at two road embankment sites.[68, 70] A comparison

Fig. 43
Relationship between settlement and time at Avonmouth

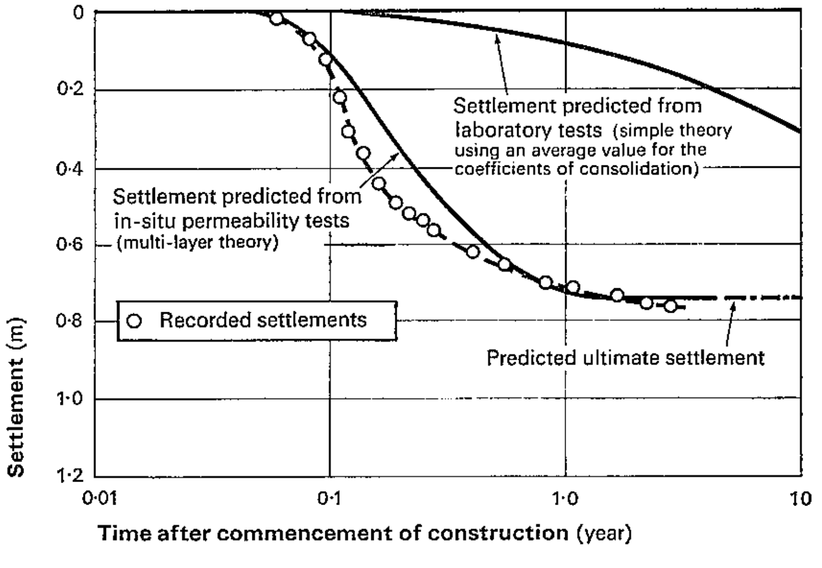
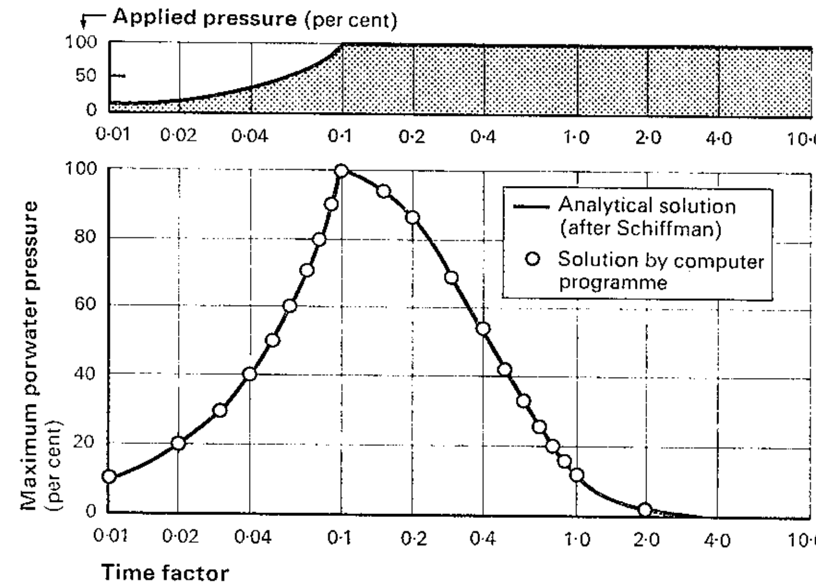


Fig. 44 Comparison between analytical and computer solutions to a problem of consolidation involving a linear role of construction loading (after Schiffman)



of the predicted and measured vertical distributions of porewater pressures at these two sites show good agreement.

Control of stability of road embankments. The stability of road embankments on deep deposits of soft subsoil is normally assessed using total stress methods of analyses. For rapid construction this design procedure can overestimate the stability whilst if the embankment is built slowly or in stages the method does not permit any allowance for the likely gain in strength of the subsoil due to consolidation.

One aim of the research in progress at the Laboratory is to develop a method of stability control based on effective stress analyses and field measurements of porewater pressure.[71] Control charts are prepared relating the calculated factor of safety to the measured excess porewater pressures for different heights of embankment. At any stage of the construction the magnitude of the porewater pressures will be governed by the response of the subsoils to the stress changes produced by embankment loading and by the amount and manner in which dissipation occurs. Both these factors are difficult to assess quantitatively in stratified deposits and certain assumptions must therefore be made for the preparation of the charts. These assumptions must be checked against the information obtained from the field measurements and if necessary modified and a new set of charts prepared. The factor of safety at any stage of the construction can then be read off the charts using the measured porewater pressures and in this way a quantitative assessment of the stability can be obtained. This method of stability control has now been employed successfully at three sites.

5.1.3 Construction of earthworks

Use of wet fill in embankments. The expense of removing wet fill regarded as unsuitable for earthworks, and replacing it by imported common fill, can form a significant part of the cost of earthwork construction. There could be a useful saving if more wet fill could be used without incurring excessive expense in handling it and without significantly lowering the performance of the embankments. Laboratory consolidation and triaxial tests have been carried out on three cohesive soils and the results used to predict the behaviour of wet fill in embankments.[72]

The work suggested that wet cohesive fill could be used at moisture contents in excess of the commonly used maximum of 1·2 times the plastic limit, in circumstances where settlements of 100 mm are acceptable. Shallow side slopes, and the use of more stable fill near formation level, may however be necessary. These restrictions could be eased by the use of horizontal drainage layers in the fill. Although the use of wet fill might reduce the efficiency of earthmoving operations the overall costs of the earthworks may be less than if imported fill is employed.

Performance of plant for compacting soils. Investigations have been made into the performance of two models of self-propelled double vibrating rollers with masses of 1·0 Mg and 7·3 Mg respectively (Plates 16 and 17).

The depths of layer used in the investigations, the number of passes required to achieve a satisfactory state of compaction, and the corresponding output of compacted soil are given in Table 15.

Tests with 7·3 Mg. double vibrating roller on the well-graded sand indicated that the outputs of compacted soil could be increased by using the second travelling gear (2·1 km/h).

Construction of earthworks using belt conveyors. Following a feasibility study of the possible use of belt conveyors for earthmoving in road construction,[73] a belt conveyor system was purchased by the Department of the Environment for the transportation of about 2×10^6 m^3 of chalk over an average distance of about 4·5 km. This operation is part of the Portsmouth Harbour Advance Earthworks contract for the M27 motorway, designed by the South Eastern Road Construction Unit. Details of the site and the belt conveyor equipment were given in *Road Research 1970,*[6] p. 24.

Following initial erection of the belt conveyor in January and February, earthmoving commenced in March 1971. In the nine months to the end of the year about $1{\cdot}4 \times 10^6$ Mg. ($0{\cdot}75 \times 10^6$ m^3 approximately) had been excavated, transported by conveyor, and placed in the area of the major interchange in the harbour. Work has been continuing throughout the winter months. Eventually it is hoped that the contract will yield information on the practicability of all-year-round working of the belt-conveyor system, the overall utilization achieved, the potential working life of the equipment and the costs of operation and maintenance.

As well as offering potential economic advantages in comparison with more conventional dump trucks or scrapers, the belt-conveyor system has virtually eliminated disturbance from noise and dust in the populated area near Portsmouth Harbour.

5.1.4 Earth retaining structures

Earth pressures and retaining structures. With the development of the programme of road construction in urban areas and the need to conserve land there will be an increasing use of earth retaining structures built below ground. Many urban areas have cohesive subsoils and considerable uncertainties exist in the design of these structures. Comparative costs of backfill materials for bridge abutments indicate that savings in the total cost could result from the use of available site fill in place of specially imported materials. The use of site fill would necessitate the placing of cohesive soils and it is with these materials that the great uncertainties exist in the calculation of earth pressures. The uncertainties in design with cohesive soils are related to the variations in strength over a period of time as a result of moisture content changes associated with the loading. For walls retaining or constructed in cohesive soils information is therefore required on the earth pressures and wall movements occurring throughout the life of the structure if economy in the design is to be achieved.

A review has been made of the problems associated with the current methods of design of retaining structures and areas for research identified.

Measurements of earth pressure in pulverised fuel ash behind a rigid retaining wall. A field investigation[74] has been carried out to measure the earth pressures developed within a pulverized fuel ash (PFA) filling behind an 11 m high retaining wall. The wall formed part of the abutment system for the Loudwater Viaduct on the M40 motorway. It was a cantilever structure of reinforced concrete 12·8 m long and restrained at its ends by the main abutments. Earth pressure cells of the vibrating wire type, were installed at four levels within the fill in a vertical profile at 1 m from the rear

Table 15: Results of investigations into the performances of the 1.0 Mg. and 7.3 Mg. double vibrating rollers in the compaction of soil (operation in low travelling gear, 1.1 km/h for each machine)

Soil	1·0 Mg. double vibrating roller			7·3 Mg. double vibrating roller		
	Depth of layer (mm)	Number of passes required	Output (m^3/h)	Depth of layer (mm)	Number of passes required	Output (m^3/h)
Heavy clay	100	Satisfactory compaction could not be achieved, even after 16 passes.		150	3	86
Sandy clay	100	5	13	260	4	110
Well-graded granular soils	130	4	21	260	4	110
Uniformly graded sand	300	3	65	Machine could not operate on loose soil.		

face of the wall (Plate 18). Thermo-couples were placed adjacent to each cell to measure the temperature of the PFA and surveys of the front face carried out at intervals to monitor the wall movements. Readings were taken during construction and for a period of 18 months after the motorway was opened to traffic.

During placing of the initial 3 m of filling above each cell the measurements showed that high lateral pressures were induced apparently by the compaction process. Over the period of observation the measured lateral pressures oscillated seasonally, an effect which seemed to be related to the changes of temperature within the fill, with an overall trend for pressures to increase. In general these pressures were greater than those assumed for the design of the wall whilst the vertical pressures were below the calculated overburden stresses. Laboratory tests showed that the ash possessed appreciable self-hardening properties. The retaining wall was massive in construction; the wall movements were very small and were probably insufficient to permit an appreciable relaxation of the lateral pressures.

5.2 Materials Section

5.2.1 Aggregates

Gritstone Survey. The Institute of Geological Sciences and the Laboratory have carried out a survey of the British resources of arenaceous rocks (gritstones, and similar rocks) with the object of finding new sources of aggregate for skid-resistant road surfacings. The survey has disclosed large resources of high quality material and has provided information that will be of value in future searches for similar material and in selecting stone within a quarry. Results show that desirable qualities (high resistance to polishing and abrasion) in arenaceous rocks are more dependent on their geological history than on their mineral composition.

Calcined Bauxite. Research has shown that few aggregates are suitable for use in resin-bound skid-resistant road surfacings. The best aggregates for this purpose are refractory grade calcined bauxites and other corundum rich materials. Further work has confirmed the exceptional properties of refractory-grade calcined bauxite (RASC-grade), but also suggests that other bauxites, if calcined under appropriate conditions, might be equally good. Bauxites from Australia, Ghana, and Northern Ireland have therefore been calcined in the Laboratory's rotary furnace at temperatures of up to 1600 °C. Laboratory tests and the interim results from road trials suggest that these materials may provide acceptable alternatives to RASC bauxite which is expensive and scarce.

Synthetic roadstone. Preliminary research[75] has shown that highly polishing-resistant synthetic roadstones can be manufactured by incorporating a hard grit into a suitable matrix. One of the most promising matrix materials is blast furnace slag, which is not only inexpensive but, by being available in the molten state, could avoid heat treatment costs, which are an expensive feature of the production of other materials of this type. A research contract has therefore been let to develop a suitable process and work has started in the Laboratory using its own rotary furnace.

5.2.2 Skidding

Development of the 'sideway-force coefficient routine investigation machine' (SCRIM). The first two production models of SCRIM have been in service during the year. Besides having more powerful engines than the prototype machine, they are equipped with a new type of recorder, in which the measured 'sideway-force coefficent' (SFC), speed and other coded data related to the site location, are provided on punched tape for direct processing by computer, in addition to the normal output in digital form.

The new SCRIM's were used in a survey of 500 km of major roads in Hertfordshire (where the county's accident records are available from a computer and are correlated with the SFC record, both being similarly coded), for assessing a selection of pedestrian crossing approaches in Greater London and for monitoring the nearside lane of the whole of the M1 motorway. The new SCRIM's were also used for routine measurements on many experimental sites which in the past were regularly tested with the earlier design of test car.

Re-assessment of standards of resistance to skidding. Analysis has continued of factors connected with revision of the standards suggested in the Report of the Committee on Highway Maintenance. The proposals for new target values of SFC will almost certainly involve two major changes. The first will be to define road categories more strictly in terms of traffic carried, and the second will be to recognize categories of site requiring the highest levels of SFC.

5.2.3 Bituminous materials

Core experiments. The Blackbushe core experiment (see *Road Research 1970*,[6] p. 97) was initiated in 1969 to study the effect on the texture depth of the source of the binder used in rolled asphalt wearing course having 30 per cent coarse aggregate but without coated chippings being applied. Textures developed slowly at first but during the second winter differences were clearly established in those cores with 7·4 per cent binder; the richer asphalts remained comparatively smooth. The experiment has established that the technique can be used to rank binders for their ability to produce a texture in rolled asphalt.

Two further core experiments have been laid during 1971. One of these is a continuation of the Blackbushe experiment, in which the performance of a further 25 binders will be studied. Many of these binders are pitch-bitumens because further investigation of the use of pitch-bitumens is considered desirable to take account of the changed sources of pitch since the carbonization of coal for town gas has ceased.

The second core experiment is designed to study the embedment of chippings in rolled asphalt when subjected to heavy traffic (see mix-design below). The two experiments have been laid in the westbound nearside lane of the A40 in the London Borough of Hillingdon (2000 commercial vehicles per day in the near-side lane).

Mix-design. The mix design of rolled asphalt wearing courses affect the penetration of the applied coated chippings during laying and rolling and their subsequent embedment by heavy traffic. Investigations by the Coal Tar Research Association in a programme of research sponsored by the Laboratory have shown that the rate of embedment of chippings in a laboratory test markedly increases with increasing binder content.

A wider range of variables including the type of binder, the content of coarse aggregate and the type of fine aggregate is also being studied and correlation with road performance is being sought in the core experiment referred to earlier.

The development of more stable mixtures to reduce the rate of embedment is complementary to studies being made to design mixtures having more reliable resistance to deformation by heavy traffic. Proposals have been drawn up for a full-scale experiment on a very heavily trafficked road to compare the performance of rolled asphalts designed using the Marshall Test and made with a variety of sands and binder contents. Pilot scale trials have been made to select the range of mixtures to be used.

Windscreen damage on surface dressings. It has been estimated that with the toughened glass windscreens used in Great Britain the rate of windscreen breakage corresponds to about one breakage every 480000 km of motoring on heavily trafficked roads. The risk on newly laid surface dressings can be much higher and 13 county authorities are co-operating with the Laboratory in an investigation designed to examine the extent of windscreen damage under these conditions on high-speed roads. Effects being studied include variations in the type of binder and of applied aggregate and methods of aftercare which include rolling and sweeping techniques and methods of traffic control adopted.

5.2.4 Concrete

Resistance to skidding. An evaluation of the resistance to skidding of sea-dredged aggregates is being made by inserting more cores into the near-side wheel track of a motorway and a trunk road, adjacent to an earlier core-insertion experiment (see *Road Research 1970*,[6] p. 99). Sea-dredged coarse aggregate has been used as well as fine aggregates containing 20 per cent and 40 per cent of shell.

Proposals have been made for assessing the reproducibility of the Accelerated Wear Machine and a co-operative programme is being carried out with the Engineering Intelligence Division of DOE and the Cement and Concrete Association.

5.2.5 SAGA co-operative research

Compactability of aggregates. Work has continued on the modification of the British Standard vibrating hammer test[76] to produce a simpler and more reliable method of assessing the compactability of graded aggregates. Reports dealing with the basic steps in the work are in preparation and will be issued shortly.

Shear strengths of aggregates. Testing has continued using the large shear box machine. The relationships between the density of packing and peak shear strengths of graded aggregates appear to obey simple laws. Reports describing the experimental work completed to date are in hand.

5.2.6 Road marking materials

Revision of British Standard. When metrication of BS3262: Part 1 : 1960[77] was proposed, it was decided to revise it completely at the same time. A working party was set up under RRL auspices in 1969 and a draft document completed in 1971. The original standard was a specification based largely on a composition recipe but the new document is based on laboratory tests for various properties viz. whiteness, softening point, heat fastness, light fastness, hot-weather flow resistance, cold-weather impact resistance, abrasion resistance, skid-resistance and acidity. Five laboratories co-operated with RRL in the development of the tests (one county, two commercial consultants, and two manufacturers).

5.3 Construction Methods Section

5.3.1 Cost and productivity of road construction

Research into the cost and productivity of plant used in the construction of road pavements has been intensified during the year. Studies have been made of production and costs of bituminous surfacings and concrete laid by conventional train and by slipform paver on five further construction contracts.

One of the purposes of the work is to identify the need for improvements in plant. One example, the requirement for a variable-width binder distributor for surface dressing work was designed by the Laboratory and in 1969 a research contract was awarded to Phoenix Engineering Ltd. of Chard, Somerset, for the development of a prototype. The new machine (Plate 19), which is built under licence from patents held by NRDC and Johnsons Ltd., has been operating in full-scale commercial development trials in Cornwall and Norfolk during the summer of 1971. Following these trials modifications to the pipework and jets have been made. During the trials carried out on minor rural roads less than about 6·5 m wide, comparisons of productivity and cost were made between the variable-width sprayer and a conventional machine. Although the prototype variable-width sprayer has a capacity of only 4500 litres whereas the capacity of the conventional sprayer is 11000 litres, the productivity using the new machine was 25 per cent greater than that of the conventional sprayer, with costs increased by only 2·5 per cent. The increase in cost results from the greater capital cost of the new machine and the need for extra lorries and, in some circumstances, a second chipping machine to maintain continuous output.

5.3.2 Organization of road maintenance

The studies described (see *Road Research 1970*,[6] pp. 103–5) have continued in collaboration with the County and Urban Working Parties on Highway Maintenance. Surveys of the highway maintenance organizations of County and Urban authorities have been carried out by questionnaire and interview. Particular aspects being studied are the methods used for costing plant and their influence on plant deployment and utilization, and the economic principles involved in the decision whether to employ a direct-labour organization on particular maintenance functions or to let the work out to contract.

One of the most important aspects of proper organization for efficient decision-making is the flow of the right kind of information to the right people. As a contribution to the improvement of the overall information and decision system, the Laboratory is supporting, by a research contract with Lindsey County Council, the development of a computerized system for estimating, programming and controlling highway maintenance and construction by direct labour or by contract. The system produces logic diagrams of works in terms of activities based on PERT networks, together with estimates for the cost of works and schedules of resources required, using work-study information to evaluate the many discrete operations which make up a complete job.

5.3.3 Testing of paving materials to establish control of manufacture and compliance with specification

A wide range of binders and aggregates are permitted in road building. Certain materials can give rise to anomalous results when their composition is analysed using present methods of testing. In recent years there have been several reports of difficulties in the determination of the composition of dense tarmacadam especially when the mixture has been prepared with slag aggregate and high-viscosity coke-oven tar binder. Apparent differences in the tar contents of samples when analysed by the simple hot extractor and by the sieving extractor methods of analysis have been noted. It has also been suggested that there was a difference in the tar content of samples taken immediately after mixing and after delivery to the laying site.

The magnitude of the differences that had been found had ranged from 0·5 to 1 per cent and in an investigation, carried out by the Laboratory in conjunction with a supplier whose material had been the subject of some dispute, 80 samples were taken from a single batch of 38 mm maximum size dense tarmacadam; one set of 40 samples was taken just after discharge from the mixer and a second set after a simulated haul lasting one and a half hours. The two sets of samples were each divided to provide two equivalent sub-sets for analysis by the two methods.

A summary of the results of the analyses is given in Table 16.

The results show that:

1. The differences in tar content between the two methods of analysis and due to the position of sampling were small.
2. There were significant differences in the percentage of aggregate passing the 3·2 mm and the 75 micron sieves due largely to the inefficiency of the dry grading process used after hot extraction.
3. The percentage of aggregate passing the 75 micron sieve determined after hot extraction was significantly more variable.

The work suggests that for the judgement of compliance with specifications a wet separation of the material passing the 75 micron sieve should be used.

5.3.4 Automatic control of asphalt mixing plant

Work is continuing on the development of fully automatic control systems using the Laboratory's pilot asphalt plant and computer-based control unit.[78]

The major source of variation in the temperature of the product in an asphalt plant is the aggregate drying and heating process in the continuous dryer. The control system which is currently being set up for the continuous dryer will use a microwave moisture meter (*Road Research 1970*,[6] pp. 107–8), to feed forward a signal proportional to the moisture content of the fine aggregate. The system is stabilized by feeding back a signal of the temperature of the dry-aggregate.

Information about the drying and heating processes is required to implement such a system successfully and experiments are being carried out to obtain data on the temperature distributions of both aggregates and gases inside the dryer under different operating conditions. The results obtained from this series of experiments will also be used in the construction of a theoretical model of the action of a continuous dryer to enable possible improvements to be identified.

Work is also in progress on a self-optimizing weighing system, which corrects automatically for long-term changes in the batching equipment and for random errors in weighing. A plant sequencing routine which will start up and monitor the plant and which initiates alarm or shut down procedures when a fault is detected is also being developed.

5.3.5 Co-operative research with the Asphalt and Coated Macadam Association (ACMA), on the compaction of bituminous materials

The team appointed by ACMA to work at the Laboratory is investigating factors which affect the spreading and compaction of bituminous bases and base-courses with the aim of obtaining materials which are sufficiently dense and uniform to achieve good pavement performance.

Table 16: Summary of analysis results

Constituent	Analysis method		
	Hot extractor	Sieve extractor	Bottle (4 samples)
Mean tar content (per cent), all samples	5·35	5·22	5·31
Standard deviation	0·39	0·34	—
Mean aggregate passing 3·2 mm sieve (per cent), all samples	41·2	45·4	45·3
Standard deviation	4·3	3·5	—
Mean aggregate passing 75 micron sieve (per cent), all samples	2·9	5·0	5·0
Standard deviation	0·46	0·25	—
Mean tar content (per cent), immediately after mixing	5·36	5·27	—
Mean tar content (per cent), on delivery to site	5·33	5·16	—

Results obtained on a pilot scale study of the effect of material temperature and number of roller passes on compaction indicated that void contents in excess of 10 per cent are possible in a dense bitumen macadam road base even when current specifications for compaction of the material are met. Such values are greater than those generally assumed to be required for a material having a satisfactory resistance to deformation under traffic. To obtain quantitative information on the standard of compaction actually being achieved in present practice cores are being taken from new construction and subsequent changes in density under traffic will be studied by a further coring programme.

Work is also in progress to determine the efficiency of various methods of compaction including the effect of pavement tampers and vibrating screeds.

The realism of future pilot-scale testing will be improved by the recent reconstruction of the test bays with a heavy clay subgrade and granular sub-base of realistic thickness.

5.4 Construction Planning Section and Scottish Branch

5.4.1 Route planning and location

Work during the past year has been continued on several computer programs in the Highway Optimization Program System. The programs were described in *Road Research 1969*,[5] pp. 109–110, and *Road Research 1970*,[6] pp. 108–110. Production versions of PRELUDE, FEASBL, JANUS and MINERVA have been completed and are being translated by the Highways Engineering Computer Branch of the DOE for use on ICL 1900 and IBM 360 computers in preparation for general issue. These programs, together with a development version of VENUS, have been operated on a London computer by the Highways Engineering Computer Branch (HECB) and used by highway engineers on 11 schemes with a total length of 171 km during the year. The average savings on earthworks costs on these schemes have been about 15 per cent. The programs have also been successfully tested for use on a railway design project in Surinam, South America.

Development on individual programs has continued as follows:

PRELUDE—The program has been extended to accept ground data cards in 'free format' and, as an alternative, to read the magnetic tape output of the digital ground model program HGROCS which is in the British Integrated Program System. Many improvements have been made to the printed output.

VENUS—The inclusion and testing of the improved routine for dealing with the design constraints is almost complete and the program will shortly be handed over to HECB for translation.

MINERVA—Much effort has been put into including error checks on the input data and into improving the presentation of the printed output. The program uses simplified road and ground cross-sections for speed of calculation and reduced storage in the computer. The volume of earthworks have been calculated with both simplified and full cross-sections and they were found to agree to within 2–3 per cent, thus justifying the use of the simplification.

THEUS—In the past, the program has assumed the cost of hauling material per unit of length along a route to be a constant value, regardless of the distance hauled. In reality, such costs tend to become reduced as the distance increases because different plant can be used which is better suited to the longer haul. The program has, therefore, been extended to take account of variations of unit cost of haul as the distance changes. Also, the program can now treat variations in soil conditions as regards cost of excavation and percentage suitability of cut for use as fill. Arrangements are being made for an earthwork contractor to run the program on a highway project so that it can be seen what developments, if any, are needed to make the program suitable for use by the contracting industry.

NOAH—Tests on three schemes have indicated that NOAH can reduce earthworks costs by at least 5 per cent in addition to the savings made by MINERVA and it is hoped that this saving will increase with further development of the program. A study is continuing to establish the width of band over which the program can operate without the assumptions about ground levels becoming inaccurate to an unacceptable amount. Further work is required to transform the output from NOAH into a conventional alignment automatically as this has been done manually in the tests.

Work on the next stage of broad band optimization has begun.

A new study has been started of the factors affecting the costs of a highway as it is necessary to develop a computerized cost model for use in these stages of the optimization which is a good deal more comprehensive than has been required previously. The study includes costs of construction, land, traffic, and social considerations.

5.4.2 Expenditure on highway maintenance

The two working parties set up to study the economics of maintenance (see *Road Research 1970*,[6] p. 111) are now engaged in a major study, the main object of which is to determine the effects of the implementation of the Marshall Committee's standards of maintenance[47] on maintenance expenditure. The study is being carried out on a sample of roads of all classes by 19 county and urban highway authorities. The condition of the road pavements and footways is being inspected and assessed in relation to the Marshall standards and the remedial work shown to be necessary is being costed. For other maintenance work such as repair of bridges, snow and ice clearance and for tasks of a cyclic nature the estimates for 1972–73 are being re-examined in the light of the Marshall standards and additional estimates are being prepared. From the total extra maintenance needs of the sample, an indication of the extra needs of the whole country will be obtained. To produce realistic figures, it is being assumed that the extra work would be spread over a five-year period. Allowance is being made for deterioration which will take place during that period. An estimate will also be made of the level of expenditure subsequently required to avoid any roads falling below the Marshall standards. A report on the study should be available by mid-1972.

Much valuable information will be obtained from the study, apart from the expenditure data. Already minor difficulties in the application of the standards themselves have been revealed. Experience in use will provide the basis for a first review of the standards which will probably be mainly directed towards rationalizing the form of presentation rather than the levels, though the expenditure data should indicate where possible changes in the levels may be necessary. The study will also yield a code of practice for carrying out the assessments on the road. The Marshall Committee's maintenance rating system is not directly being tried out in this study but the data being obtained will assist towards the determination of suitable levels for the weighting and traffic factors incorporated in the system and the development of the system generally.

The study was set up with manual processing of the field data in view, but the Laboratory is preparing a computer program for processing the data to a stage at which the engineer can make his cost estimates.

5.4.3 Scottish Branch

The Scottish Branch continues to play an active part in the work of the Scottish road industry. Although the Branch is primarily studying the design, construction and maintenance of roads, the advisory and information service also covers the fields of traffic and safety. Some examples of the work being carried out are given below.

Use of unburnt colliery shale in road construction. A survey has been carried out into the use of unburnt colliery shale for embankment construction in major road contracts in England and Scotland. No difficulties were reported and, in general, it was found to be easier to lay and compact in wet weather than many soils. There were no reports of spontaneous combustion and the likelihood of this occurring in embankments compacted to current standards is now considered to be remote.

Frost susceptibility of road-making materials. As part of an investigation into the reproducibility of the RRL frost-heave test,[79] eight testing laboratories carried out the test on three standard specimens—a slag, a gravel, and a whinstone. It was found that the reproducibility of the frost-heave test was poor and on the basis of the results obtained it would have been difficult to use the test as a valid means of control. Future work will be aimed at improving the test procedure by identifying and, if possible, eliminating the sources of variability.

A start has been made on a programme of research to investigate the effect of variations in the depth-to-water-table on the heave in road pavements which incorporate frost susceptible materials. A new cold-room has been installed with a specially designed 2 m deep pit in the floor in which road structures can be built up and the height of the water-table can be varied. A range of sub-base and base materials will be tested with the object of determining whether some relaxation of the present specified limits can be allowed where a low water-table is assured.

Salt for winter maintenance. A survey is being carried out in Scotland on the use of salt for winter maintenance. There have been reports that imported salts are not as easy to spread nor as effective as salt from UK sources and the survey will show the extent of these and any other problems and whether they warrant investigation.

Advisory and liaison work. During the year a large volume of enquiries was dealt with, many of which were followed by on-site investigation. Two very successful one-day symposia were held in Glasgow. The subjects discussed by more than 200 engineers from Scotland and Northern England were 'Road Construction and Maintenance in Areas of Mining Subsidence' and the third edition of Road Note 29.[80]

5.5 Tropical Section

5.5.1 Transport planning in developing countries

Highway design study. This study which is being undertaken with the collaboration of the International Bank for Reconstruction and Development is designed to enable total transport costs to be minimized for any particular project (see *Road Research 1970*,[6] p. 119). Field studies on experimental road sections in Kenya began in May. The sample consists of 93 sections of 2 km comprising 12 earth roads, 43 gravel roads, 34 surface-dressed roads with cement-stabilized bases and 4 roads with bituminous carpet on a crushed rock base. It includes roads in high and low rainfall areas having a range of geometric characteristics; similar sections are being subjected to different maintenance routines. Measurements being carried out cover the deterioration of the road surface in relation to road standard, climate, traffic, soil type and level of maintenance and, through the use of test vehicles, the effect of road geometry and surface condition on vehicle speed and fuel consumption. Other aspects of vehicle operating costs are being studied using a sample of vehicles selected from the commercial vehicle population and consisting of 120 buses, 80 lorries and 30 motor cars. Detailed records are being kept for these vehicles and the routes over which they operate are being evaluated.

Rural traffic. Examinations of a number of road feasibility studies have shown that design standards and rates of return are frequently very sensitive to estimates of traffic flow and rates of growth. Furthermore, an analysis of extensive data obtained from studies in Kenya and several other developing countries[81] has shown that the levels of accuracy associated with commonly-used traffic census methods for estimating current flow and consequently predicted flows, can rarely be expected to be within ±30 per cent of the true value averaged over the whole year. Any appreciable improvement in estimates of traffic flow will require the continuous operation of automatic traffic counters at fixed locations.

Land-use/transportation. The study of the future transport needs in Nicosia in relation to land-use planning to the year 2000 has been completed and a report issued.[82] The results of the study show that by the year 2000 the number of motor vehicle trips per day in Nicosia would rise from 70000 to about 500000. To cater for this demand, capital required would exceed probable resources and for this reason, even accepting the most suitable road layout, some restraint on car use at peak hours will be needed. It is thought that the best method of achieving the necessary restraint will be through the control of parking together with improved public transport facilities. It is planned to conduct further studies on the question of restraint of vehicle use to relieve congestion in cities in developing countries.

User costs. The majority of road feasibility studies concentrate on vehicle operating cost savings to provide project justification. Following studies carried out in Kenya on the values placed on road user journey times,[83] it was decided that a case existed for using journey time savings in future feasibility studies in developing countries. This procedure was followed in a recently completed study of a road in Mauritius where it was found that, whereas vehicle operating cost savings amounted to £0·33 million potential savings that would arise through reductions in journey time were £2·25 million. Thus it appears that the inclusion of journey time savings could have a very important effect on project viability; because of this, further studies are to be carried out on the economic worth of journey time savings in developing countries.

5.5.2 Road survey practice and terrain evaluation

Geophysical surveys. Work has continued on the assessment of geophysical techniques for all types of engineering surveys. A report[84] has been published describing the use of seismic refraction techniques in a feasibility study in St Lucia. Surveys were made in a mountainous region to estimate the thickness of soil over hard rock. The results show that, when drilling is impracticable, seismic refraction provides an alternative means of investigation that is sufficiently accurate to permit the estimation of the cost of earthworks in a feasibility study.

Seismic refraction surveys have been used in West Malaysia to determine the depth of weathering in granite in a range of terrain conditions. This information will be incorporated into the terrain evaluation study of the area. A report is being prepared giving details of the seismic surveys, and including a comparison of a single-channel seismograph using a hammer and a multi-channel recording seismograph actuated by explosives.

An electrical resistivity survey has been made in Kenya of areas which are to be used to provide gravel for road construction. Data have been obtained on resistivity values of a range of tropical gravels. The objects of this work are to provide a quick method of locating areas of suitable roadbuilding gravel, and also to guide the extension of existing borrow pits.

Terrain evaluation. Work has continued on the projects reported in *Road Research 1970*,[6] p. 116. A land system map has been drawn of the survey area in West Malaysia, and this is being prepared for printing by the Directorate of Overseas Surveys. Two reports are being prepared, the first describing the techniques of land classification for engineering surveys and the second the land systems of the survey area.

The study of the relationship between engineering soils and units of terrain continues with the collection of soil test data and earthworks quantities. In Kenya, this information will be catalogued under the unit in which it occurs and statistically analysed to assess the variability of each unit. Detailed contoured maps of selected areas in West Malaysia have been prepared photogrammetrically to estimate the quantities of earthworks engendered by different terrains.

A research team left for Colombia early in 1971. The work will include the identification of the different types of landsliding, and relating them to a land classification of the country.

5.5.3 Pavement design and evaluation

Research has continued on the use of deflection techniques, both automatic and manual, for the structural evaluation of pavements in the tropics and the design of strengthening overlays for them. A Deflectograph has been operated in the Trucial States to investigate the deflection characteristics of bituminous-bound pavements at high temperatures and to test the reliability of the machine in these conditions. In September the Deflectograph was transferred to Iran to carry out a pavement reconstruction design exercise in association with a conference in Tehran organized by the CENTO Scientific Secretariat. Long-term deflection studies continue in Malaysia and Ghana aimed at establishing appropriate deflection criteria for strengthening tropical roads. A paper[85] describing a survey procedure using hand deflection beams and their use in designing overlays was presented to a seminar organized by the Indian Roads Congress.

The effect of very heavy wheel loads in reducing the life of pavements is especially marked in many developing countries, where pavements are generally lightly built and the regulation of vehicle weights is not always effective. To enable information on axle loads to be gathered, a portable weighbridge has been developed[86] and surveys have been carried out with this apparatus in the Trucial States, Iran and Kenya during 1971.

A knowledge of the factors affecting moisture movements in subgrades under tropical roads is of great importance to the design engineer and, whilst much is known of the influence of the basic factors, further quantitative information is required on the effect of different verge treatments on subgrade moisture in markedly seasonal climates. Two road sites in Kenya have been instrumented to investigate the effect of verge slope and cover on the subgrade moisture condition and a research contract has been awarded to the University College of Nairobi to analyse and report on the data accruing over three years from these experiments.

Pavement materials. The construction of the full-scale experimental road in Qatar, Arabian Gulf, designed to compare the performance of various bituminous surfacings in very hot conditions (see *Road Research 1970*,[6] p. 114) was completed in March. Measurements of deformation, transient deflection and surface condition made six months later indicated that no significant differences in performance between the different surfacings had developed in that time.

The research being carried out in the field into the design and construction of soil-cement bases has continued. Fuller details of the current work are given in two reports.[87, 88]

5.5.4 Training and education

A lecture course on road planning, construction and maintenance held in Kuala Lumpur in March in co-operation with the University of Malaya and Shell Malaysia Ltd. was very successful and attracted 95 participants, 40 being from other countries in South-East Asia. Another such seminar was held in Trinidad in September in co-operation with the University of the West Indies and the Caribbean Development Division and was attended by 54 engineers from the Caribbean and Latin America. This seminar was followed by a week-long course for 50 senior technicians and appropriate road-building technology was demonstrated.

In the United Kingdom a short residential course aimed at post-graduate students from overseas was held in April and was attended by 33 participants from 15 different countries.

Nine highway engineers from Nepal, Burma, Colombia, Sudan and Sarawak were attached to the Tropical Section for training during the year.

5.5.5 Advice on road planning and building, including capital aid schemes

The staff effort devoted to advising the Overseas Development Administration, other United Kingdom Government Ministries, consulting engineers, contractors, and overseas governments totalled six man-years during 1971.

In addition to general advisory visits to overseas countries, the following countries were visited to advise on specific projects or to present papers at conferences: Botswana, Cyprus, Ethiopia, Guyana, Iran, Kenya, Malaysia, Nepal, Seychelles, Thailand, and Turkey.

6.1 Computer Section

6.1.1 The computer service

During 1971 Computer Section continued to provide a comprehensive computer service to the Laboratory and certain other parts of the DOE. The service is based on a large ICL 4–70 computer which is operated centrally by staff of the Section: in general the Computer Section does not undertake applications programming, because research workers themselves write programs to solve their particular problems. In this they are aided by an advisory and training service provided by Systems Group.

The throughput of the service has continued to rise throughout the year. In January an average of some 1000 user jobs were processed every week, and by September this had increased to about 1300. It was also possible to provide a better turnround of computer jobs—and this is a most important factor for research workers for whom program development is a more or less continuous activity. At the end of 1970 about 30 per cent of user jobs were turned round within 3 hours, and 90 per cent within 24 hours: by mid-1971 these figures had reached 50 per cent and 95 per cent.

These improvements have been achieved without any increase in the number of hours the computer is used, and is due to several causes: increases in the efficiency of the operating teams, improvements in ICL operating software, and perhaps primarily the enhancement of 4–70 by two major pieces of hardware. In April a set of large-capacity exchangeable disc files (EDS 30) was brought into use. This provides about 230 million characters of on-line storage for the program and data files of the many users of the system, and obviates the need to batch users work and to make frequent changes of on-line storage discs. In September the capacity of the core-store was increased by 50 per cent when a further 131 thousand characters was added. This was done principally in order to support multi-access computing which is planned (see Section 6.1.2 below), but in the meantime the additional core has served to hasten batch operations by increasing the level of multi-programming.

6.1.2 Plans for multi-access computing

A major activity has been to plan for the provision of multi-access computing (available at a set of keyboard terminals distributed round the Laboratory) in addition to the present batch service. This has involved trials, in conjunction with users, of a new ICL operating system called MULTIJOB. The aim of this work is to give the research worker direct and immediate access to the power of the large machine from a terminal near his place of work, and to reduce the frustration of a centralized batch service. Present plans envisage the multi-access service starting in spring 1972.

6.1.3 Management computing

Two projects have been undertaken in 1971 for Administration Division. Work is in progress on a new version of the Management Information and Costing System which will provide new facilities and cope with the expansion of the Laboratory. The system provides management with cost information (in cash and manpower terms) on all RRL activities for use in planning, monitoring, and control: the new system is to be implemented in spring 1972. In addition, a computer suite has been provided to give progress information on all the jobs undertaken by Engineering Services. The suite provides more useful outputs than before, and eliminates a deal of tiresome clerical work.

6.1.4 Accounting for computer resources

There is an obvious need to monitor the use of computer resources by the many users of the service. A new RRL-written system was introduced in January which is closely linked to the operating system of 4–70, and produces detailed information on the resources used by every job which is run. The outputs from it have been useful in understanding and streamlining operations, and also in providing management information on computer use.

7. ADMINISTRATION AND SERVICES DIVISION

This Division is responsible for the general administration of staffing, financial matters, and central technical services required to support the research effort.

7.1 Administration

7.1.1 General Services Section

This Section is concerned with matters requiring policy decisions and the application of those decisions to the day-to-day work. Among the wide range of subjects covered the major task is the compilation of the Laboratory's research programme together with the annual and forward-look estimates of effort and finance. Allied to this activity are the extramural research contracts and other research at universities financed by grants from the Research Councils. The Section also provides secretarial services for the RRL Research Committees and the Section Head acts as Secretary to the Laboratory's Management Board.

Its other functions include the patenting of Laboratory inventions, the negotiation of property rights agreements in connection with the development contracts placed in industry, legal and parliamentary matters, and the organization of conferences and meetings of international research groups with which the Laboratory is associated.

During the last year the level of activity in most areas has increased considerably. In particular the Section was heavily involved in the preparations for the Open Days at Crowthorne in May 1971.

7.1.2 Executive Services Section

One of the prime duties of the Section is to relieve the research staff of the day-to-day routine tasks which would otherwise fall to them: for example, the registration and custody of papers, arrangements for visits abroad, assistance with housing problems, etc. The Section is also responsible for recruitment and staff records, accounting and financial control, and for contractual matters including the negotiation of research and development contracts with industry and co-operative research contracts with other organizations working in related fields.

During the year there has been an overall increase of 57 in the staff of the Laboratory, the total non-industrial staff increasing to 728 whilst the industrial staff has remained fairly constant at around 259. In addition, 1852 casual and short-term helpers have been recruited at various times during the year, mostly for a few days at a time, in connection with experiments on the Laboratory's research track.

Expenditure during the year on equipment services and research contracts increased by approximately 27 per cent over the previous year reaching a new peak of £1·4 million. The total number of contracts and orders placed rose by 8·7 per cent to 12500. This year has seen the inception of research and development contracts with industry on a larger scale than hitherto. Those placed and under negotiation include work in connection with the development of an experimental safety vehicle, a demonstration quiet noise level heavy vehicle, and tunnelling methods.

7.2 Training and Courses

7.2.1 Training

Following the transfer of the RRL from MOT to DOE, proposals referred to in *Road Research 1970*[6], p. 121 for the introduction of a local RRL Career Development Scheme have been deferred until the new Departmental policy and organization have been settled. A start is to be made in providing the necessary staff complement for running internal training courses early next year.

Availability of science graduates improved dramatically during 1971 and this not only affected recruitment but also altered, for the first time for many years, the pattern of training requirements for the young entry scientific staff. Thus there was less demand for GCE and ONC Courses, while requirements for post-graduate training increased. The Laboratory made a significant contribution to University Engineering and Scientific Degree education by providing increased numbers of places for suitable sandwich course students for Industrial Training. During 1971 there were 45 such students at the Laboratory for six months each (a few for up to nine months) covering 10 disciplines.

7.2.2 RRL Courses

The 1971 programme covered the following four courses:

Control and Compliance—four days.

Pavement Design—two courses each of three days.

Senior Police Course—five days.

In all a total of 220 attended the four courses, compared with 400 people attending the nine courses held the previous year. The two main factors accounting for the reduction in the courses programme were: first, the Open Days in May, and second, the provision of Flexible Roads Courses now in the Surrey University programme, being run in collaboration with the RRL and ACMA.

7.3 Information Services Section

The function of the Information Services Section is to disseminate the results of the Laboratory's work and to provide information on road research for a wide audience.

To achieve this objective two specialist groups use modern communication techniques to publicize the work of the Laboratory and operate a technical information service for research workers, practising engineers, and the public.

7.3.1. Press and Publications Group

The activities of the group cover most aspects of Press Office procedure including participation in radio and television programmes, press conferences and exhibitions. Lectures on the Laboratory's work are given to local organizations by a Press Officer.

During the year the Laboratory's Open Days were held and a there was a record attendance of 15000. Many visitors were from overseas, representing local authorities, consultants, contractors, students and professional bodies.

The Open Days were preceded by a Press Day during which over 200 journalists representing both the British and overseas press attended. Further coverage of the event was made possible by British and overseas television.

As the work of the Laboratory has become more widely known so the number of applications to visit the Laboratory has increased. A large proportion of the visitors were from abroad.

Over 200 Laboratory reports, papers and articles were published during the year. The Group has also produced a number of 'special' publications including a *Computer Handbook, Opportunities for Graduates* pamphlet, reports for ODA and brochures for both the Scottish and the Crowthorne Open Days.

A range of other publicity material has also been produced including: posters, information leaflets, and press notices.

7.3.2 Technical Information and Library Group

The work of the Laboratory's team of abstractors and information scientists reflects the changing emphasis in the Laboratory's field of research, and to a lesser extent the current interests of research workers in the road research and allied fields. The vast amount of literature to be scanned and analysed for subsequent retrieval makes heavy demands on the staff available, and it is only through membership of the International Road Research Documentation (IRRD) scheme that it has been possible to keep pace with published work and on-going research. Whenever possible use is made of authors' abstracts, either in the original or modified form, and it is hoped that more editors and publishers will provide this facility. Whereas before 1965 the Group was responsible for worldwide coverage, now, in general, English language publications only are scanned. The rest of the literature is abstracted and indexed as a co-operative effort by other IRRD members.

The Laboratory has played a large part in the development and testing of the specification for magnetic tape transfer of IRRD records, due to be implemented in January 1972. The specification and associated procedures were explained, demonstrated and discussed at a Plenary Meeting organized by OECD and held at the Laboratory in October 1971. The meeting was attended by some 60 delegates from both documentation and computer services in 14 IRRD member countries. A major part was played in the planning of the Plenary Meeting; the Head of the Group was Chairman of the Meeting and also gave two of the lectures; lectures were also given by three other members of the Group and by a member of the Laboratory's Computer Section.

The number of technical enquiries dealt with, including literature searches using the computerized retrieval system, is now approaching

3000 per annum, and the impression from visitors attending the Open Days and from correspondence is that this service is proving very useful.

In addition to its technical information service, RRL Reports published during the year were distributed. The Library's holdings in the field of transportation have increased during the year to meet the needs of the newly created Transportation Division within the Laboratory. More calls have been made on the Library services and on the interpretation and translation services provided.

7.4 Photographic Services

The demands on the Photographic Section continue to grow, as the services are expanded into wider photographic fields to meet the Laboratory's Research commitments.

To handle these requirements the work is spread between five main groups, all of which are serviced by a photographic workshop.

7.4.1 Trials and Instrumentation Group

This group is responsible for providing high-speed and time-lapse cinematography for subsequent analysis and inclusion in documentary films.

Over the past year its main efforts have been concerned with time-lapse studies of pedestrian crossings, mini-roundabouts, and Channel Tunnel experiments.

A high-speed cinematography service has been provided for research on crash barriers, seat belts, and bus seats, and extensive coverage of windscreen destruction tests for the safety car project have been undertaken on the dynamic test rig.

7.4.2 Film Unit

Seven sound and a number of silent documentary films have been completed this year. All stages of film production were covered from the initial shooting, processing, sound recording and editing to the final release print. Films on most aspects of the Laboratory's work are made available to interested organizations for loan or purchase.

The Unit is responsible for the audio visual services, sound recording, tape editing, and projection facilities. In addition closed circuit television and video tape recording is being increasingly used on research projects.

7.4.3 Stills Group

This Group has participated fully in the Laboratory's programme of experimental and publicity work. Preparation for and coverage of RRL Open Days, the series of Channel Tunnel experiments, and the M27 Portsmouth Harbour Advance Earthworks contract have been the major assignments.

7.4.4 Reprographic Group

Reproduction for RRL Open Days dominated this years work. The new feature of special reports added interest to the bulk of the work, which consisted of printing, duplicating or copying the Laboratory's reports, circulars and notes.

7.4.5 Scientific applications

The work of the scientific applications group is directly concerned with the development and utilization of photography as an aid to research. This aspect of photography ranges from day to day advice on existing systems, to long-term evaluation and development of new techniques. The Group is at present engaged in various new techniques including analytical photogrammetry, long period time lapse, aerial photography and remote traffic survey systems.

The main work priority has been given to immediate research needs including photomicrography, macrography, graticules, endoscope photography, sensitometry, photometry, and chronocyclography.

7.5 Engineering Services

7.5.1 Experimental equipment design

The main activity of the Group continues to be in the provision and development of special purpose equipment for use in the research sections of the Laboratory. This work involves the writing of feasibility and design studies and drawing up technical specifications for contracts, with ultimate responsibility for acceptance of equipment. Design, both mechanical and electrical/electronic, is also a feature of the work.

Examples of projects are:

Bridge vibration. A propulsion system for a vibrating trolley, traversing a model bridge to simulate a moving road vehicle. A range of trolley speeds is available up to a maximum of 6 m/s. The essential feature is that no forces are imparted to the trolley by the propulsion device other than the towing force. Propulsion is achieved by a wire cable driving through a variable speed gear. A linear motor was seriously considered for this purpose but the limited availability of motors with low thrust coupled with problems in protecting power supply and the effect of arcing on the associated instrumentation eventually ruled it out.

Deflectograph. The normal recording system with this equipment gives analogue traces of road deflection from which the maximum deflection per cycle is obtained by reference to a calibration scale.

A prototype of a new development has been constructed to provide a direct output of these maxima in punched paper tape form. The system scans the output of the two sensors and logs the greater. Additionally a keyboard is provided for the insertion of reference data and values of road surface temperature. This new development will eliminate the tedious analysis of analogue traces and represents a significant advance in the routine monitoring of the stiffness of road constructions.

SCRIM. Several developments have taken place following the success of the prototype machine in measuring the skidding condition of road surfaces. Most of these have resulted in improved performance and reliability of the mechanical aspects. Particular attention has been paid to the recording system which originally produced a printed output of sideway force coefficient, vehicle speed and reference data, the latter being set up by starwheel switches. An interim development was similar in operation but provided an output in punched paper tape form. The most recent development has a much larger facility for reference data with keyboard insertion as well as a range of coded event markers and other new operational features. The Section has provided liaison with manufacturers and potential users of SCRIM equipment both in this country and overseas. This work has included a specification for a special version having test wheels in both nearside and offside tracks for use in limited urban areas where traffic conditions do not always permit the vehicle to be suitably positioned for testing with a nearside wheel only.

Rotary furnace. Development and commissioning of a rotary furnace using an oxygen/propane gun for the production of synthetic aggregates continued. Work involved initial trials, installation of safety features and proposals for routine operation and maintenance.

7.5.2 Drawing Office

The Drawing Office continues to provide support for Experimental Equipment Design Group and a general design and drawing service for the Laboratory. Examples of work are:

- A 325 m length of noise barrier for the M4 motorway.
- Plastic pipe deformation sensor.
- Sieving extractor.
- Camera mountings on an aircraft.
- Core density determination apparatus.

The scope of the work covers both mechanical and electrical/electronic equipment, the latter including circuit diagrams, printed circuit layout and artwork.

7.5.3 Technical Illustrations

The main feature of the work during the year was the responsibility for the design and production of 320 large display panels for the Open Days, and for work on the brochure, leaflets, maps and descriptions of the exhibits.

General work of the Group included illustrations for direct use in research, the provision of some 350 illustrations for projection slides and the illustrative work appearing in all official publications including this report.

7.5.4 Civil Engineering

In addition to the normal provision of services and facilities in direct support of the research programmes and for the day to day running of the Laboratory services, the Section played a major role in the provision of services for the Open Days at the Crowthorne site. Because of the greatly increased work load, consulting engineers were employed for the first time to carry out survey and design work and to help with the supervision of contracts. Amongst the special facilities provided during the year, directly under the control of the Section were:

1. Full size simulated channel tunnel trains of 10 special carriages each, used for experiments carried out during the year including the period of Open Days.
2. Weathering sites up and down the country at places as diverse as Silverdale, Lancashire, and Portishead, Somerset.
3. Vehicle guidance and detector cable system (RITA), a number of these being in the section of the M4 between Holyport and Theale opened at the end of the year.
4. A reinforced concrete structure with approach roads for work in connection

with the effects of the level of water table on the distribution of stress and strain in a flexible road.

5. New roadside accommodation has been provided in connection with experiments taking place at locations remote from the main Laboratory, e.g. on sites adjacent to the new sections of the M4 and at the Applied Psychology Unit, Cambridge.

Planning continued throughout the year on existing and proposed development schemes to be carried out for the Laboratory by the Central and Regional Housing and Construction units of the Department. Contracts were let for two schemes for the Crowthorne site, an office/laboratory block to house 150 research staff and an additional section to the research track to meet the special demands of research into road-user training and behaviour. Construction work commenced on a special pilot-scale building for research work on the structural properties of underground pipes. A further contract was let for a special temperature controlled chamber at the Livingston premises for research into the effects of frost heave on various road making materials.

7.5.5 Workshops and transport

An increase in normal workload, together with Open Days, has made this a very busy year for Workshops and Transport Sections and some work normally carried out in-house has been placed with outside contractors. Typical jobs are a new experimental sieving machine for Construction Methods Section and 12 spring-powered motors and recorders for rainfall measurement for use by Environment and Tropical Sections. Work continues on dynamic weighbridge manufacture and servicing SCRIM, and boring rig modifications. All new work is designed and manufactured to metric dimensions, with 75 per cent of the machines being calibrated in dual metric/imperial units. There is a gradual improvement in the availability of metric materials and components.

The wood-working shop produced 320 basic display boards for Open Days, fitted out a mobile laboratory and built a headlight display unit as well as other work for research projects.

The electrical/electronic work included the design and manufacture of a digital readout Wind Vane Logger, modifications to parts of the asphalt coating plant for computer control and the installation of strain gauges and equipment on bridges at various sites. Assistance was given to some Road Construction Units in the fixing of strain gauges to determine stresses in new motorway bridges.

During the year 39 staff obtained Heavy Goods Vehicle licences and 20 additional vehicles and items of plant were purchased. Six cars and six coaches were prepared for impact tests.

7.5.6 Fire and safety

The incidence of accidents related to the working force (ie the number of accidents per 1000 workers) was below that of the previous year, with the incidence rate at 22·3 compared with 25·3 last year. The use of the frequency rate as a measurement of safety performance has been discontinued as HM Factory Inspectorate and similar establishments have ceased to publish figures for comparison.

There were seven minor fires, four of which were associated with buildings and three with plant, machinery, and vehicles. Training staff in the use of fire fighting equipment continued, with emphasis on new recruits and staff working in high risk areas.

An investigation was commenced to measure the dust concentrations generated by an experimental asphalt mixing plant and sieving configuration using various materials and housed within a pilot-scale laboratory. It included the determination of percentage of quartz and the amount of respirable dust. Consideration was also given to various methods of dust removal and cost.

Sources of ionizing radiation are still being used for non-destructive testing, analyses, and measurement, and the number of staff on the work has been fairly constant. No recorded doses were over the safe permissible level.

Pulsed lasers are now being used in connection with work on road profilometry and the staff have been instructed in safety measures.

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9.1 RRL REPORTS

LR 355 Tyre performance in wet surface conditions: G. C. Staughton and T. Williams.

LR 366 Report to the Marshall Committee on the organization and standards of highway maintenance.

LR 367 The Marshall Committee's recommendations for standards of highway maintenance and for a maintenance rating system.

LR 370 Full-scale road experiments using rubberized surfacing materials: P. D. Thompson and W. S. Szatkowski.

LR 371 Traffic census results for 1969: J. B. Dunn.

LR 372 The value of time savings from road improvements: J. D. G. F. Howe.

LR 373 Calculations of stresses, strains and displacements in a layered elastic structure, part II: E. N. Thrower.

LR 376 Tests to determine the design of roadside soft arrester beds: I. B. Laker.

LR 377 Road accident tabulations language (RATTLE): P. Harris.

LR 378 The performance of two self-levelling headlamp systems: J. S. Yerrell.

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Annex No. 1: Bristol
Annex No. 2: Chesterfield
Annex No. 3: Leicester
Annex No. 4: Watford
Annex No. 5: Luton
Annex No. 6: Reading
Annex No. 7: Preston
Annex No. 8: Sheffield
} Not generally available

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LR 409 The influence of visual pattern on perceived speed: G. G. Denton.
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LR 412 Relations between compressive and indirect-tensile strengths of concrete: R. E. Franklin and T. M. J. King.
LR 413 Public transport journey times in London—1970: D. A. Lynam and P. F. Everall.
LR 414 Rural road distribution in Kenya: J. D. G. F. Howe.
LR 415 Amplitude control and detection in an electrohydraulic dynamic loading system: P. B. Still.
LR 416 Car journey times in London—1970: D. A. Lynam and P. F. Everall.
LR 417 Benefit assessment for network traffic models and application to road pricing: M. R. Wigan.
LR 418 A survey of traffic-induced vibrations: A. C. Whiffin and D. R. Leonard.
LR 419 Embankments constructed on soft foundations; settlement study at Avonmouth: R. T. Murray.
LR 420 Measuring the effectiveness of area traffic control systems: Joyce Holroyd and D. Owens.
LR 421 Traffic delays due to resurfacing of M4 motorway 1970: A. D. Maclean.
LR 423 The effect of strength on performance and economics of concrete pavements: J. M. Gregory.
LR 424 The use of seismic refraction in a route feasibility study in St. Lucia: M. Stewart.
LR 425 Nicosia transportation study; 1968–70: E. Dalby and G. D. Jacobs.

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10. APPENDIX 2: ADVISORY COMMITTEES

10.1 RESEARCH COMMITTEE ON BITUMINOUS MATERIALS

Terms of reference

'To advise on the planning, conduct and application of research into the design, manufacture and laying of road materials containing flexible binders.'

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P. C. Gane, F.I.C.E., M.I.H.E.	Lincolnshire County Council (parts of Lindsey)
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C. E. Hingley	Tarmac Roadstone Holding Ltd.
H. Jennings, M.B.E., B.Sc.(Eng.), M.I.C.E., M.I.Struct.E.	Directorate of Civil Engineering Development, Department of the Environment
R. R. C. Johnson, M.B.E., C.Eng., M.I.C.E.	South Eastern Divisional Road Engineer Organization, Department of the Environment
D. McNeil, O.B.E., B.Sc., Ph.D., F.R.I.C., M.I.Chem.E.	The Coal Tar Research Association
K. R. Peattie, B.Sc., Ph.D.	Esso Petroleum Co. Ltd.
G. J. Rayner	The Amey Group Ltd.
L. R. Robertson, M.Sc., A.C.G.I., F.I.C.E., F.I.Mun.E.	Southampton Corporation
R. P. Sleep, C.Eng., M.I.C.E., F.I.Mun.E.	Engineering Intelligence Division, Department of the Environment
P. W. Tebbutt	Wirksworth Asphalt Ltd. (retired)
W. R. Thomson, M.I.C.E., M.I.Mun.E., F.Inst.H.E.	Worcester County Council

10.2 RESEARCH COMMITTEE ON BRIDGES

Terms of reference

'To advise on the planning, conduct and application of research into problems arising in the design, construction, maintenance and use of bridges, viaducts, flyovers and overhead roads.'

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D. Dennington, B.Sc.(Eng.), A.C.G.I., M.I.C.E.	Greater London Council
A. R. Flint, B.Sc.(Eng.), Ph.D., A.C.G.I., F.I.C.E., M.Cons.E.	Flint and Neill, Consulting Engineers
G. B. Godfrey, M.I.C.E., F.I.Struct.E.	Constrado
A. Goldstein, B.Sc.(Eng.), A.C.G.I., D.I.C., F.I.C.E., F.I.Struct.E., M.Inst.H.E., M.Cons.E.	R. Travers Morgan and Partners (Consultants)
L. R. Greenaway, O.B.E., B Sc.(Eng.), C.Eng., F.I.C.E.	Bridges Engineering Technical Approvals Branch, Department of the Environment
W. Henderson, M.B.E., D.Sc., F.I.C.E., M.Inst.H.E., S.I.C.F.	Scottish Development Department
R. B. Hill, B.Sc., C.Eng., F.I.C.E., F.I.Struct.E.	Cementation Construction Ltd.
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10.3 RESEARCH COMMITTEE ON CONCRETE

Terms of reference

'To advise on the planning, conduct and application of research in the design, construction and maintenance of concrete roads and bases including cement.'

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Professor T. E. H. Williams, M.Sc., Ph.D., F.I.C.E., M.I.Struct.E., M.Inst.H.E.	University of Southampton

10.4 RESEARCH COMMITTEE ON DESIGN AND CONSTRUCTION

Terms of reference

'To advise on the planning, conduct and application of research into soils, earthworks and drainage, and the structural design of roads.'

Chairman

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D. R. Sharp, M.B.E., B.Sc., D.Sc., Dip.T.P.(Lond.), C.Eng., F.I.C.E., F.I.Mun.E., F.I.Struct.E., F.Inst.H.E.	Cement and Concrete Association
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Professor H. B. Sutherland, S.M., F.I.C.E., F.I.Struct.E., F.R.S.E.	Glasgow University
M. J. Tomlinson, F.I.C.E.	George Wimpey and Co. Ltd.
O. T. Williams, C.B.E., M.A.(Cantab), C.Eng., F.I.C.E.	Sir Owen Williams and Partners
T. D. Wilson, B.Sc., F.I.C.E., F.I.Struct.E., F.I.Mun.E., M.I.H.E.	North Western Road Construction Unit, Department of the Environment

10.5 RESEARCH COMMITTEE ON ROAD SAFETY

Terms of reference

'To advise on the planning, conduct and application of research on road safety as it affects the road user and the design of roads and road vehicles.'

Chairman

H. Taylor, B.Sc., A.C.G.I., C.Eng., M.I.Mech.E.	Road Research Laboratory, Department of the Environment

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P. J. Chapman, M.B.	Medical Research Council
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M. A. Macaulay, B.Sc., Ph.D., C.Eng., F.I.Mech.E.	Motor Industry Research Association
J. McGowan	British Leyland Motor Corporation Ltd.
J. T. Manuel	Home Office
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K. J. B. Teesdale, B.E.(Tas.), M.I.Mech.E.	Ford Motor Company
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10.6 RESEARCH COMMITTEE ON ROAD TRAFFIC

Terms of reference

'To advise on the planning, conduct and application of research on road traffic and the interaction of the technical problems with economics.'

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Sir Herbert Tetley, K.B.E., C.B., M.A.	Government Actuary's Department
J. O. Tresidder, M.Eng., F.I.C.E., A.M.Inst.H.E., M.C.I.T.	Freeman, Fox and Associates
Professor R. White, B.Sc., F.I.C.E.	University of Newcastle upon Tyne
C. P. J. Woods	New Scotland Yard

10.7 RESEARCH COMMITTEE ON TUNNELS

Terms of reference

'To advise on the programme, conduct and application of research on tunnels, including their planning, design, construction and operation.'

Chairman

R. S. Millard, C.M.G., B.Sc.(Eng.), Ph.D., C.Eng., F.I.C.E., M.I.Struct.E., M.Inst.H.E.	Road Research Laboratory, Department of the Environment

Members

H. Allenby, C.Eng., F.I.C.E.	The Tyne Tunnel
J. Armour, C.Eng., F.I.C.E., F.I.Mun.E., M.T.P.I.	Glasgow Corporation
J. V. Bartlett, M.A., C.Eng., F.I.C.E., M.A.S.C.E.	Mott, Hay and Anderson
N. Borg, F.I.C.E., F.I.Mun.E.	City of Birmingham Corporation
W. Burns, C.B.E., D.Sc., M.Eng., C.Eng., M.I.C.E., P.P.R.T.P.I.	Planning Services Division, Department of the Environment
Brigadier J. Constant, M.A., C.Eng., F.I.C.E., F.I.Mech.E., M.I.E.E., M.Inst.T.	Channel Tunnel Studies Unit, Department of the Environment
L. R. Greenaway, O.B.E., B.Sc.(Eng.), C.Eng., F.I.C.E.	Bridges Engineering Technical Approvals Branch, Department of the Environment
D. A. Harries, B.Sc.(Eng.), C.Eng., F.I.C.E.	The Mitchell Construction Kinnear Moodie Group Ltd.
S. T. Jones, C.Eng., F.I.C.E., F.I.Mun.E.	The Mersey Tunnel
J. S. Moulder, T.D., C.Eng., F.I.C.E., F.I.Mun.E.	Greater London Council
A. M. Muir Wood, M.A., C.Eng., F.I.C.E.	Sir William Halcrow and Partners
L. B. Mullett, B.Sc., C.Eng., M.I.E.E.	Chief Scientific Adviser's Group, Department of the Environment
Professor E. L. J. Potts, M.Sc., C.Eng., F.R.I.C.S., F.I.Min.E., M.I.M.M.	University of Newcastle upon Tyne
Sir Norman Rowntree, B.Sc., C.Eng., F.I.C.E., M.I.W.E.	Water Resources Board, Department of the Environment
R. L. Triggs, B.Sc., C.Eng., F.I.C.E.	Edmund Nuttall Sons & Co. Ltd.
F. S. P. Turner, C.Eng., F.I.C.E.	London Transport
W. H. Ward, D.Sc.(Eng.), C.Eng., A.C.G.I., F.I.C.E.	Building Research Station, Department of the Environment

10.8 WORKING GROUP ON RESEARCH INTO ROAD TRAFFIC NOISE

Terms of reference

'To review the state of knowledge of traffic noise, and current research into the subject in this country and abroad; to identify those fields of traffic noise research where increased effort is needed; to co-ordinate traffic noise research within the United Kingdom and to encourage the exchange of information with other countries; to advise on the use of traffic noise research findings.'

Chairman

R. S. Millard, C.M.G., B.Sc.(Eng.), Ph.D., C.Eng., F.I.C.E., M.I.Struct.E., M.Inst.H.E.	Road Research Laboratory, Department of the Environment

Members

M. E. Burt, B.A., F.R.Ae.S.	Road Research Laboratory, Department of the Environment
M. E. Delany, B.Sc., Ph.D., D.I.C.	National Physical Laboratory, Department of Trade and Industry

J. L. Dickinson, A.R.I.B.A.	Research and Development Group, Department of the Environment
A. E. Fieldhouse	Engineering Intelligence Division, Department of the Environment
J. W. Fitchie, B.Sc.(Eng.), Ph.D., C.Eng., M.I.Mech.E., M.S.A.E.	Road Research Laboratory, Department of the Environment
A. E. Haines, C.Eng., M.I.Mech.E.	Mechanical Engineering Division, Department of the Environment
Professor N. S. Kirk, B.A., Ph.D., F.S.S.	Loughborough University of Technology
A. Lassiere, M.Sc.(Eng.), B.A.	Urban and Regional Professional Division, Department of the Environment
S. J. Leach, B.Sc., Ph.D.	Building Research Station, Department of the Environment
C. H. G. Mills, B.Sc.(Eng.), A.K.C.I., C.Eng., F.I.E.E.	The Motor Industry Research Association
Professor T. Priede, Inz. Mech. Latvia, Ph.D.(Lond.), D.Sc.(Eng.), M.I.Mech.E.	Institute of Sound and Vibration Research, University of Southampton
Commander E. Tyrell, M.I.Mech.E., M.R.I.N.A., M.I.Mar.E.	Department of Trade and Industry
G. H. Vulkan, B.Sc., A.Inst.P.	Greater London Council
L. H. Watkins, B.Sc., C.Eng., M.I.C.E., M.Inst.H.E., F.R.Met.S.	Road Research Laboratory, Department of the Environment

10.9 PANEL ON UNDERGROUND PIPES

Terms of reference

'The Panel should be responsible for the overall planning and supervision of the Research Programme outlined in paragraph 223 of the Second Report of the Working Party on the Design and Construction of Underground Pipe Sewers 1967, and its co-ordination with relevant research elsewhere.'

'The Panel should report to the Working Party and to the Director of Road Research.'

'The Director of Road Research is responsible for the execution of the Research Programme.'

Chairman

M. E. Burt, B.A., F.R.Ae.S.	Road Research Laboratory, Department of the Environment

Members

D. Croney, B.Sc., Ph.D., C.Eng., F.I.C.E., M.Inst.H.E.	Road Research Laboratory, Department of the Environment
L. H. C. Evans, M.I.C.E., A.M.I.W.E., M.R.S.H.	Directorate of Civil Engineering Development, Department of the Environment
I. Hainsworth, F.I.C.E.	Department of the Environment (retired)
J. M. Haseldine, M.A., F.I.C.E., M.I.Mech.E.	John Taylor and Sons
T. P. Hughes, M.I.C.E., M.I.Mun.E.	Directorate of Water Engineering, Department of the Environment
O. C. Young, B.Sc., M.I.C.E.	Building Research Station, Department of the Environment

11. APPENDIX 3: EXTRA-DEPARTMENTAL RESEARCH SPONSORED BY THE LABORATORY

University or Research Association	Research project	Approximate duration (years)
University of Aberdeen	Conceptual problems in teaching road safety to children	3
Asian Institute of Technology, Bangkok	Linked signals and roundabouts	1
Asian Institute of Technology, Bangkok	Investigation into suitable sites for specified co-operative traffic experiments	$\frac{1}{3}$
University of Birmingham	Influence of dynamic loading on physical and structural properties of unbound aggregate road making materials	2
University of Birmingham	Measurement of vibration transfer of vehicles	$\frac{1}{2}$
Brunel University	The effects of gradients on traffic noise	1
Building and Road Research Institute, Ghana	The burning characteristics of various types of African limestone	1
University of Cambridge	Ultimate load analysis of multi-cellular reinforced concrete bridge decks	3
The Coal Tar Research Association	Factors in hot rolled asphalt and asphaltic concrete mix design which affect workability and permeability	2
The Coal Tar Research Association	Methods for making standard bituminous test specimens	$1\frac{1}{2}$
University of Liverpool	Prestressed cables in curved ducts	$2\frac{3}{4}$
Manchester Business School, University of Manchester	Research programme planning at the Road Research Laboratory	2
The Motor Industry Research Association	Experimental Safety Vehicle—Impact properties of materials and components	1
The Motor Industry Research Association	Design, manufacture and testing of the cab for a prototype quiet heavy vehicle	3
The Motor Industry Research Association	Design, manufacture and testing of the cooling system for a prototype quiet heavy vehicle	3
The Motor Industry Research Association	Design, manufacture and testing of the exhaust system for a prototype quiet heavy vehicle	3
National College of Agricultural Engineering	Erosion by rainfall run-off of roadside shoulders, embankments and cuttings in Kenya	3
University of Nairobi	Analysis of volume changes and moisture distribution in road beds in Kenya	2
Newcastle upon Tyne Polytechnic	Effects of road gradients, traffic stops and traffic composition on urban traffic noise	3
University of Newcastle upon Tyne	Mechanical cutting characteristics and properties of lower chalk	$1\frac{1}{4}$
The Coal Tar Research Association	Effect of variable of mix design on the resistance of embedment of chippings into hot rolled asphalt	2
Construction Industry Research and Information Association	Preparation and painting of rusty steel	$3\frac{1}{2}$
The Electrical Research Association	Wind loadings on bridges	1
The Institution of Highway Engineers (at Oxford Polytechnic)	Pedestrian accidents in residential areas	3
Imperial College of Science and Technology	Measurement of exposure risk to pedestrians in urban areas	1

University or Research Association	Research project	Approximate duration (years)
Imperial College of Science and Technology	Environmental aspect of odour from traffic	½
Imperial College of Science and Technology	Fatigue of pre-stressed concrete beams	2
Imperial College of Science and Technology	Attention-attracting value of flashing lights in daylight and at night	3
Imperial College of Science and Technology	Composite construction of bridges	3
Imperial College of Science and Technology	Motorway surface water drainage	3
Institute of Computer Science University of London	Computer programs for highway design	1
Kings College, London	East African rainfall	3
University of Lancaster	Hydrology of upland catchments	3
University of Leeds	Relationship between perceptual defect, as shown by reading disability, and road accidents in children of school age	1
University of Nottingham	The importance of skill as a factor in child pedestrian accidents	3
University of Nottingham	Permanent deformation of flexible paving materials	3
University of Nottingham	The identification of factors leading to road accidents in young children	3
University of Nottingham	Fatigue properties of bituminous road mixes	4
Paint Research Station	Testing of paint primers on bridges	3
University of Reading	Vibration instrumentation for bridges	2
University of Salford	Development and evaluation of motor cycle training schemes	2
University of Salford	Bus demonstration project	1
University of Salford	Effectiveness of using appeals based on fear in road safety propaganda	2
University of Salford	Evaluation of a scheme for teaching children to drive	5
Institute of Sound and Vibration Research, University of Southampton	Design, manufacture and testing of the engine, gear box and air intake for a prototype quiet heavy vehicle	3
University of Southampton	Teaching road safety to children	3
University of Southampton	Before and After studies of a bus priority scheme in Bitterne Road, Southampton	1⅔
University of Strathclyde	Area traffic control in Glasgow	4
University of Strathclyde	Effect of water on road bitumens	3
University of Surrey	Evaluation of properties of cement-stabilized materials in tension	1
University College, London	Traffic intensity in urban areas	1½
	Total Grant	£784 500

12. APPENDIX 4: LIST OF INDUSTRIAL RESEARCH CONTRACTS

	Industrial contracts	Firm
1	Cost/Productivity study	Fitzpatrick & Son (Contractors) Ltd.
2	Cost/Productivity study	Richard Costain (Civil Engineering) Ltd.
3	Synthetic aggregates	Sandberg
4	Wheel loading pad	British Hovercraft Corporation Ltd.
5	Bus passenger routeing	Systems and Marketing Consultants
6	Passive seat belts	Auto Restraint Systems Ltd.
7	Inflatable bag	Auto Restraint Systems Ltd.
8	Road pricing equipment	Plessey Company Ltd.
9	Appraisal of vehicle identification unit	Mackintosh Consultants Co. Ltd.
10	Road pricing equipment	McMichael Ltd.
11	Bus demonstration project	Partners in Management Ltd.
12	Noise survey, Alton	Electrical Research Association
13	Merge signalling system	Throughways Transport Ltd.
14	Reading travel survey	Local Government Operational Research Unit

13. APPENDIX 5: CO-OPERATIVE RESEARCH WITH INDUSTRY

13.1 CO-OPERATIVE RESEARCH WITH ASSOCIATIONS

The Laboratory has arrangements for co-operative research with the following Associations:

(i) *SAND AND GRAVEL ASSOCIATION OF GREAT BRITAIN*
Programmes of co-operative research to cover the use of sand and gravel in road construction with particular reference to tar-bound and bitumen-bound materials including work on granular sub-bases.
Four SAGA staff, appointed in 1966–67, continue to work at the RRL. See Section 5.2.5.

(ii) *REFINED BITUMEN ASSOCIATION*
Research into the performance of bitumen-bound mixtures under repeated loading, including fatigue cracking, elasticity and flow. Two RBA staff have continued to work on this project during 1970, paying particular attention to the effects of rest periods on fatigue life. See Section 4.2.1.

(iii) *BRITISH TAR INDUSTRY ASSOCIATION*
A survey of the performance of tarmacadam bases and basecourses in experimental and non-experimental roads has been completed by the two BTIA staff. Attention has been transferred to laboratory tests of tar-bound materials under repeated loading. See Section 4.2.1.

(iv) *ASPHALT AND COATED MACADAM ASSOCIATION*
Research into compaction, density and workability of bituminous mixtures. See Section 5.3.5.

(v) *INTERNATIONAL DRIVER BEHAVIOUR RESEARCH ASSOCIATION (BRITISH PETROLEUM CO. LTD.)*
Studies into driver behaviour.

13.2 JOINT WORKING PARTIES

Joint Working Parties or periodic discussions are arranged with the following Associations and Federations:

(i) Asphalt and Coated Macadam Association
(ii) Cement and Concrete Association
(iii) British Quarrying and Slag Federation
(iv) Automobile Association.

14. APPENDIX 6: FULL-SCALE EXPERIMENTS BEGUN DURING THE YEAR

14.1 DESIGN DIVISION

14.1.1 BRIDGES BEHAVIOUR

Stresses in cellular box bridges

Object: Distribution of stress in a multi-cellular concrete box bridge under live and dead loading.

Thames Bridge, Marlow–Bisham By-pass

Stresses in steel box girders

Object: Stress in flanges, webs, and diaphragms of a steel box girder, in the region of the supports, during and after erection.

Cleddan Bridge, Milford Haven

14.1.2 STRUCTURAL PROPERTIES

Instrumented pervious surfacing experiment

Object: To monitor the flow of water through the pervious surfacing under rain storm conditions.

A40 at Northolt

14.2 TRAFFIC DIVISION

14.2.1 TRAFFIC SYSTEMS

New junction designs

Traffic signals replaced by 'hollow-island' mini-roundabouts.

(1) Lido and Eastover junctions on A38, Bridgwater, Somerset
(2) A39/A390 Arch Hill junction, Truro, Cornwall

Single oblong roundabout replaced by double mini-roundabout. Borough Engineer's scheme, RRL observations.

A12/Cowdray Avenue junction, Colchester, Essex

14.3 TRANSPORTATION DIVISION

14.3.1 URBAN TRANSPORT PLANNING

Urban travel characteristics

Object: A travel survey in the Reading area. RRL has appointed the Local Government Operational Research Unit as consultants to undertake the survey in collaboration with the local authorities and public transport operators in the area. Data were collected from household and roadside interviews, measurements of traffic volume and composition, postcard questionnaires for bus and rail passengers, journey time and junction delay measurements. The results of the 1971 survey will be compared with those obtained in 1962 at RRL with the object of refining transportation planning methods.

Reading

Urban speed/flow measurement by aerial survey

Object: The development of a satisfactory method of deriving urban traffic speed/flow data from aerial survey records.

Difficulty has been experienced in obtaining suitable equipment for this project, but work is continuing to develop a means of recording and processing data on area traffic speed/flow by means of air survey.

Bristol and other urban areas

14.3.2 ENVIRONMENT

Air pollution

Object: To measure the atmospheric pollution caused by vehicle exhaust emissions and to relate this to traffic flow and composition, and to other relevant factors.

Measurements have been and are being made of carbon monoxide, lead, and other pollutants at a range of sites, and traffic and weather data are being recorded. At some sites noise also is being recorded (see below).

Birmingham, Reading, M1, M4 and other areas

Traffic Noise

Object: To measure the noise created by road traffic and to determine how it is affected by traffic flow and composition, and by building layout.

Measurements have been and are being made at a range of sites and computer mapping techniques are being employed. At some sites air pollution is also being measured (see above).

Birmingham, Reading, and other areas

15. APPENDIX 7: ORGANIZATION OF THE ROAD RESEARCH LABORATORY ON 31 DECEMBER 1971

Director of Road Research
A. Silverleaf, B.Sc., C.Eng., F.R.I.N.A.
Personal Secretary: Mrs J. M. Miller
Deputy Director
R. S. Millard, C.M.G., B.Sc. Ph.D., C.Eng., F.I.C.E., M.I.Struct.E., M.Inst.H.E.
Personal Secretary: Mrs V. M. Clark
Assistant Director (Administration)
G. Charlesworth, D.Sc., Ph.D., C.Eng., M.I.C.E., F.Inst.P.
Personal Secretary: Mrs F. E. Ryley

15.1 DESIGN DIVISION

M. E. Burt, B.A., C.Eng., F.R.Ae.S., M.I.C.E. (Head of Division)
Personal Secretary: Mrs S. R. Gawan

15.1.1 Bridges Behaviour Section

W. I. J. Price, B.Sc., M.Sc., C.Eng., M.I.C.E., M.Inst.H.E. (Head of Section)
R. R. Bishop, B.Sc., Ph.D., F.I.Corr.T. (PSO)
W. P. M. Black, B.Sc. (PSO)
C. P. Young, B.Sc. (PSO)
D. W. Cullington, B.Sc. (SSO)
J. S. Hay, B.Sc. (SSO)
J. Prudhoe, B.Sc., Ph.D. (SSO)
M. E. Taylor, B.Sc. (SSO)
Miss M. Emerson, B.Sc. (HSO)
D. S. Moss (HSO)
A. R. H. Price (HSO)
D. E. Steed (HSO)
C. Beales, B.Sc. (SO)
A. Fulbrook (SO)
J. S. Hutchings, B.Sc., G.R.I.C. (SO)
M. R. Jones, B.Sc. (SO)
S. D. Lock (SO)
M. McKenzie, B.Sc. (SO)

15.1.2 Bridges Design Section

J. A. Loe, B.Sc., C.Eng., M.I.C.E. (PSO) (Acting Head of Section)
D. R. Leonard, B.Sc., C.Eng., A.F.R.Ae.S. (PSO)
D. E. Nunn, M.A., C.Eng., M.I.E.E. (PSO)
J. Wills, M.A. (PSO)
L. C. P. Yam, B.Sc., Ph.D., D.I.C. (PSO)
M. A. Crisfield, B.Sc., Ph.D. (SSO)
P. C. Das, B.Tech., Ph.D. (SSO)
J. W. Grainer (SSO)
G. E. Higgins, B.Sc., C.Eng., M.I.C.E., M.I.Mech.E. (SSO)
S. A. H. Morris (SSO)
H. G. B. C. Mott, M.A. (SSO)
G. H. Sparks, B.Sc., M.Eng.Sc. (Aust.) (SSO)
R. Eyre (HSO)
H. Howells (HSO)
C. A. K. Irwin, C.Eng., A.F.R.Ae.S. (HSO)
M. D. MacDonald, Grad.I.Mech.E., Grad.I.C.E. (HSO)
C. S. Clarke (SO)
J. R. Cuninghame (SO)
D. Kingston (SO)
I. Newell, B.Sc. (SO)
J. Page, B.Sc. (SO)

15.1.3 Pavement Design Section

D. Croney, B.Sc., Ph.D., C.Eng., F.I.C.E., M.Inst.H.E. (Head of Section)
P. D. Thompson, B.Sc., M.Inst.H.E. (PO)
J. J. Trott, B.Sc., M.Inst.P. (PSO)
P. J. Williamson, B.Sc. (PSO)
E. W. H. Currer (SSO)
J. Gaunt (SSO)
J. M. Gregory (SSO)
J. C. Jacobs (SSO)
E. E. Lock (SSO)
P. Nath, B.Tech., M.Sc. (SSO)
J. R. Nowak (SSO)
Miss M. E. Page (HSO)
R. A. Snowdon (HSO)
C. D. Hudson (SO)
J. N. Neal (SO)
P. J. Norman, B.Sc., A.M.I.C.E. (SO)
M. G. D. O'Connor (SO)
J. B. Stevens (SO)
H. G. Longlands, B.Sc., C.Eng., M.I.C.E., A.M.Inst.H.E., A.M.I.W.P.C. (MGE)

15.1.4 Structural Properties Section

D. F. Cornelius, B.Sc. (Head of Section)
D. G. W. Mace, B.Sc., C.Eng., S.M.I.E.E.E., M.I.E.E. (PSO)
K. D. Raithby, B.Sc., C.Eng., A.F.R.Ae.S. (PSO)
E. N. Thrower (PSO)
S. J. Thurlow, B.Sc. (PSO)
H. M. Harding (HSO)
H. C. Mayhew, C.Eng., M.I.E.R.E., M.B.S.S.M. (HSO)
J. T. Ramshaw, C.Eng., M.I.Mech.E. (HSO)
A. H. Wilson, B.Sc. (HSO)
L. W. E. Castledine (SO)

A. C. Whiffin, O.B.E., B.Sc., M.Sc., Ph.D., C.Eng., M.I.Mech.E. (Dis-PSO)
R. R. Addis, B.Sc., M.Inst.P. (SSO)
H. Dinmore (SSO)
F. B. Fawcett, B.Sc., M.Sc., A.M.I.Struct.E. (SSO)
J. Galloway, C.Eng., M.I.Mech.E. (SSO)
E. N. Gatfield (SSO)
J. F. Potter, B.Sc., M.Inst.P., M.B.S.S.M. (SSO)
A. B. Sterling, Dip.Tech. (SSO)
J. R. Brown (HSO)
D. R. C. Cooper, M.Inst.P. (HSO)
A. R. Halliday (HSO)
B. C. J. Chaddock, B.Sc., Ph.D. (SO)
D. S. Faulkner (SO)
M. E. Fellows, B.Sc. (SO)
A. S. Nagarkatti, B.E. (SO)
R. G. Robinson, M.Sc. (SO)
R. J. Spalding, B.Sc., A.M.I.C.E. (SO)
P. B. Still, B.Sc. (SO)
W. J. H. Treble, B.A., M.Sc. (SO)
R. A. Whitmarsh (SO)
M. A. Winnett (SO)
J. C. Young (SO)

15.1.5 Tunnels Section
M. P. O'Reilly, M.E., C.Eng., M.I.C.E., M.I.E.I., A.M.Inst.H.E. (Head of Section)
R. G. Tyler, B.Sc., C.Eng., M.I.C.E., M.I.Struct.E. (PSO)
R. S. Bartlett, M.A. (SSO)
C. McCaul (HSO)
G. I. Crabb (SO)
J. M. Morgan, B.Sc. (SO)
A. P. Munton, B.Sc., M.Sc. (SO)
D. G. Simpson, B.Sc. (SO)
J. L. Tyler, B.Sc. (SO)
H. J. Hignett, C.Eng., M.I.Mech.E., A.M.I.E.D. (MGE)

15.2 CONSTRUCTION DIVISION
J. H. Nicholas, M.A.M.Inst.H.E. (Head of Division)
Personal Secretary: Mrs M. Clark

15.2.1 Construction Methods Section
N. W. Lister, B.Sc., C.Eng., M.I.C.E., M.Inst.H.E. (Head of Section)
G. D. Goodsall, B.Sc. (PSO)
R. Hardman, B.Sc. (PSO)
*F. H. P. Williams, M.A., C.Eng., M.I.C.E. (PSO)
P. G. Jordan, B.Sc. (SSO)
J. Macleod (SSO)
B. S. Parmenter, C.Eng., M.I.C.E., A.M.Inst.H.E. (SSO)
D. S. Wilson (SSO)
Miss M. H. Bradbury (HSO)
A. T. W. Christopher (HSO)
I. H. Czarnecki (HSO)
A. C. Edwards (HSO)
I. E. Lancaster (HSO)
J. C. McLellan, Dip.C.E. (HSO)
S. A. Sharpe, D.F.C. (HSO)
R. Abell, B.Sc. (SO)
S. G. Bond (SO)
R. S. Coutts (SO)
B. W. Ferne, B.Sc. (SO)
I. A. Ladipo, B.Sc. (SO)
P. A. Looker (SO)
R. J. Mead (SO)
P. B. P. Rossiter (SO)
Mrs M. E. Thomas, B.Sc. (SO)
R. Weeks, B.Sc. (SO)
H. Harper (TWO II)

*Seconded to the Ministry of Overseas Development

15.2.2 Earthworks and Foundations Section
W. A. Lewis, B.Sc., C.Eng., F.I.C.E., M.Inst.H.E. (Head of Section)
M. J. Dumbleton, B.Sc., Ph.D., M.Inst.P., F.G.S. (PSO)
D. M. Farrar, B.Sc., M.Sc., M.Inst.P. (PSO)
A. W. Parsons (PSO)
I. F. Symons, B.Sc., A.M.Inst.H.E. (PSO)
B. A. Broad (SSO)
M. J. Irwin, M.Inst.M.C. (SSO)
R. T. Murray, B.Sc., A.M.Inst.H.E. (SSO)
R. G. Pocock (SSO)
G. West, F.G.S. (SSO)
J. D. Bethell, B.Sc. (HSO)
J. E. Cross (HSO)
H. C. Ingoldby (HSO)
D. McLaren (HSO)
A. D. Marsh, B.Sc., M.Inst.P. (HSO)
M. D. Ryley, B.Sc. (HSO)
P. Darley, B.Sc. (SO)
M. A. Huxley, B.Sc. (SO)
J. V. Krawczyk (SO)
A. F. Toombs (SO)

15.2.3 Materials Section
G. F. Salt, M.Eng., C.Eng., F.I.C.E., M.Inst H.E. (Head of Section)
J. R. Hosking, M.Sc., A.C.S.M., A.I.M.M. (PSO)
J. G. James (PSO)
A. Please, B.Sc., M.Inst.H.E. (PSO)
W. S. Szatkowski, B.Sc. (PSO)
R. E. Franklin, B.Sc., C.Eng., M.I.C.E., A.M.Inst.H.E (SSO)
E. H. Green, M.Sc., A.R.I.C. (SSO)
F. A. Jacobs, B.Sc. (SSO)
W. E. Gibbs (HSO)
T. M. J. King, B.Sc. (HSO)
M. M. Miller (HSO)
L. W. Tubey (HSO)
A. Calder (SO)
D. R. Hanger (SO)
Mrs G. G. Neville, B.Sc. (SO)
Miss C. Palmer, B.Sc. (SO)

G. C. Woodford (SSO)
N. Wright (SSO)
M. E. Daines, Grad.I.E.R.E. (HSO)
R. M. Snell (SO)
E. W. H. Spry (SO)
W. Szafran (SO)

15.2.4 Construction Planning and Scottish Branch
G. Margason, D.L.C., C.Eng., M.I.C.E., A.M.Inst.H.E. (Head of Section)
M. H. Milloy, B.Sc., Ph.D. (PSO)
J. P. Stott, B.Sc., Ph.D., C.Eng., M.I.C.E. (PSO)
P. J. F. Wingate, M.C., M.A., M.Inst.H.E. (PSO)
H. E. H. Davies, B.Sc., A.M.I.C.E. (SSO)
C. K. Fraser (SSO)
D. S. Moncrieff, M.Inst.H.E. (SSO)
B. J. O'Connell (SSO)
C. H. Peters (SSO)
D. E. Weller (SSO)
J. Burns, B.Sc. (HSO)
M. E. Chard, B.Sc., Grad.I.M.A. (HSO)
L. H. Swanson (HSO)
J. M. W. Brown, B.Sc. (SO)
K. J. Henderson (SO)
W. G. Keir (SO)
G. R. Pryce, B.A. (SO)
J. Pynn, B.Sc. (SO)
R. Robinson, B.Sc., A.M.I.C.E. (SO)
K. H. Withey, B.Sc., A.M.I.C.E. (SO)

15.2.5 Tropical Section
E. D. Tingle, B.Sc., Ph.D., M.Inst.H.E. (Head of Section)
M. R. Anderson, B.Sc., M.Sc., C.Eng., M.I.C.E., M.Inst.H.E. (PSO)
P. J. Beaven, B.Sc. (PSO)
H. E. Bofinger, B.E., M.E., Ph.D., C.Eng., M.I.E. (Aust.) (PSO)
R. S. P. Bonney, B.Sc. (PSO)
J. N. Bulman, D.L.C., C.Eng., M.I.C.E., M.Inst.H.E. (PSO)
J. W. F. Dowling, B.Sc., F.G.S. (PSO)
E. Dalby, B.Sc., A.M.Inst.T.E., A.M.Inst.H.E., F.G.S. (SSO)
M. N. Daniel, Dip.C.E. (SSO)
C. I. Ellis, B.Sc., C.Eng., M.I.C.E., A.M.Inst.H.E. (SSO)
H. Hide, B.Sc. (SSO)
L. S. Hitch (SSO)
J. D. G. F. Howe, B.Tech., M.Sc., A.M.I.C.E. (SSO)
C. J. Lawrance, B.Sc. (SSO)
F. P. Potocki, B.Sc. (SSO)
S. W. Abaynayaka, A.M.Inst.T. (HSO)
B. F. Buglass (HSO)
Mrs J. L. B. Campe, M.A. (HSO)
G. D. Jacobs, L.R.I.C., A.M.Inst.H.E. (HSO)
T. E. Jones (HSO)
D. Newill (HSO)
A. E. Pollard, A.M.Inst.H.E., F.G.S. (HSO)
H. R. Smith (HSO)
M. Stewart, L.R.I.C. (HSO)
G. A. Sullivan, A.Inst.Sc.Tech. (HSO)
A. R. Wright (HSO)
C. G. Duffell, B.Sc. (SO)
Miss P. Hutchinson, B.A. (SO)
Miss L. L. Kempson, B.Sc. (SO)
R. B. C. Russell, B.Sc. (SO)
J. D. Boardman, B.Sc., C.Eng., M.I.C.E. (MGE)
J. W. Hodges, C.Eng., M.I.C.E., A.M.Inst.H.E. (MGE)
C. J. D. Lane, B.Sc., M.Sc., C.Eng., M.I.C.E., A.M.I.E. (Aust.) (MGE)

15.3 TRAFFIC DIVISION
A. J. M. Hitchcock, B.A., Ph.D., M.Inst.P. (Head of Division)
Personal Secretary: Mrs P. F. Folland

15.3.1 Computer Section
M. Grimmer, B.Sc. (Head of Section)
H. C. Hall, B.Sc., M.Sc., M.B.C.S. (PSO)
H. C. Parten (PSO)
J. G. Dennis, B.Sc. (SSO)
P. Harris, B.Sc. (SSO)
K. E. Perrett, B.Sc. (SSO)
Mrs S. M. Walmsley, B.Sc., M.Phil., D.I.C. (SSO)
W. R. Bellini, B.Sc. (HSO)
Mrs P. M. Beaumont (Exec.O)
A. M. Dorman (Exec.O)
D. C. Holder (Exec.O)

15.3.2 Traffic Management and Control Section
J. A. Hillier, B.Sc. (Head of Section)
B. D. Armstrong, M.A. (PSO)
Mrs J. Holroyd, B.Sc., M.Sc., Ph.D., F.S.S. (PSO)
P. D. Whiting, B.Sc. (PSO)
I. A. G. Gillies, M.B.E., B.A. (Principal)
D. H. Blackmore (SSO)
P. F. Everall, M.A. (SSO)
J. F. Collins (HSO)
P. Gower, B.Sc. (HSO)
C. F. Lucas, Grad.I.Mech.E. (HSO)
J. Montague (HSO)
D. Owens, BSc. (HSO)
J. K. Smith (HSO)
R. D. Bretherton, B.Sc. (SO)
W. F. Jones (SO)
C. J. Lines, B.Sc. (SO)
Miss E. S. Matthews, B.A., M.Sc. (SO)
I. A. Sayer (SO)
B. G. Stoneman (SO)
C. C. Thomerson, B.Sc. (SO)

15.3.3 Public Transport Section

F. V. Webster, B.Sc., Ph.D. (Head of Section)
T. M. Coburn, B.Sc. (PSO)
A. J. Finnamore, B.Sc., C.Eng., M.I.E.E. (PSO)
P. H. Bly, B.Sc., Ph.D. (SSO)
M. A. Cundill, B.Sc., Ph.D., M.Inst.P. (SSO)
P. B. Ellson, A.M.I.M.I. (SSO)
G. R. Green (HSO)
J. D. Parry, Grad.I.Mech.E. (HSO)
M. D. Bardsley, B.Sc. (SO)
G. A. Coe, B.Sc. (SO)
B. R. Cooper, B.Sc. (SO)
R. N. Gupta (SO)
D. M. J. Hale, B.Sc., A.C.G.I. (SO)
R. E. Layfield, B.Sc. (SO)
J. D. Longmore (SO)
R. H. Oldfield, B.Sc. (SO)
M. W. Pickett (SO)
P. F. Watts, B.Sc. (SO)

15.3.4 Traffic Systems Section

G. Maycock, B.Sc., M.Inst.P. (Head of Section)
F. C. Blackmore, A.F.C., Dip.E.P.U.L. (PSO)
D. H. Mathews, B.Sc., F.R.I.C. (PSO)
N. C. Duncan (SSO)
J. B. Dunn, M.A. (HSO)
R. C. Halsall, B.A. (HSO)
M. Marlow, B.Sc., Dip.Tech. (HSO)
R. Richards (HSO)
C. S. Fraser, B.Sc. (SO)
A. D. Maclean, B.Sc. (SO)
Mrs G. M. Morris, B.Sc. (SO)
Miss M. Page, B.A. (SO)
M. J. Philbrick, B.Sc. (SO)
C. P. Sawers, B.A. (SO)

15.4 SAFETY DIVISION

H. Taylor, B.Sc., A.C.G.I., C.Eng., M.I.Mech.E. (Head of Division)
Personal Secretary: Mrs R. P. Shrives

15.4.1 Accident Analysis Section

F. Garwood, O.B.E., M.A., Ph.D., F.S.S. (Dis-PSO) (Head of Section)
C. R. Faulkner, B.Sc., Ph.D., A.I.M. (PSO)
I. D. Neilson, B.Sc., M.Sc., D.I.C., A.K.C., C.Eng., A.F.R.Ae.S. (PSO)
R. F. Newby, B.Sc., F.S.S. (PSO)
J. E. Eaton (SSO)
G. C. Staughton, C.Eng., M.I.Mech.E. (SSO)
H. A. Wilkins, B.Sc. (SSO)
Miss D. P. Chapman (HSO)
P. J. Codling, L.R.I.C. (HSO)
Mrs H. Green, B.Sc. (HSO)
H. D. Johnson (HSO)
Mrs P. O. Palmer, M.A. (HSO)
C. R. Gent, B.A., Dip.Stats. (SO)
M. J. Godley, B.Sc., F.S.S. (SO)
F. J. James (SO)
M. S. Richards, B.A., M.Sc., F.S.S. (SO)
Miss V. J. Storie (SO)

15.4.2 Drivers Aids and Abilities Section

H. A. J. Prentice, M.Sc., C.Eng., A.F.R.Ae.S., F.Inst.P. (Head of Section)
A. Irving, M.Sc. (PSO)
J. A. Martin, B.Sc. (PSO)
S. B. Penoyre, B.A., D.A.E. (PSO)
Miss B. E. Sabey, B.Sc., M.Inst.H.E., F.Inst.P. (PSO)
J. S. Yerrell, B.A., M.Inst.P. (PSO)
J. S. Armour, C.Eng., M.I.E.R.E. (SSO)
K. H. F. Cardew, C.Eng., M.I.Mech.E. (SSO)
L. Cooper (SSO)
G. G. Denton, A.(SA)I.E.E., A.M.I.E. (SSO)
P. L. Harms (SSO)
R. A. F. Priest (SSO)
J. A. Reid (SSO)
K. S. Rutley, B.Sc. (SSO)
A. E. Walker, M.Inst.P. (SSO)
D. C. West, B.Sc., Ph.D. (SSO)
D. J. Jeffrey, B.Sc. (HSO)
L. Johnson, C.Eng., M.I.E.E. (HSO)
R. C. Moore (HSO)
S. P. F. Petty, M.A. (HSO)
J. R. Spindlow (HSO)
K. V. Buchta (SO)
I. D. Carter (SO)
J. A. Cobb, B.Sc. (SO)
J. S. Dobson (SO)
E. Macneill (SO)
G. G. Richards, B.Sc. (SO)
C. Willis, B.Sc. (SO)

15.4.3 Road User Characteristics Section

K. Russam, B.Sc., M.Inst.H.E., M.Inst.P. (Head of Section)
S. J. Older, B.Sc. (PSO)
J. Inwood, B.Sc., M.Inst.P. (SSO)
S. W. Quenault, B.Sc. (Prin. Psych.)
D. Sheppard, B.A., Ph.D. (Prin. Psych.)
G. B. Grayson, B.Sc. (Sen. Psych.)
Mrs D. E. Firth, B.Sc. (Psych.)
J. P. Henry, B.A. (Psych.)
Miss H. V. Colborne, B.A. (HSO)
R. D. Fairhead (HSO)
A. M. Mackie, M.A. (HSO)
B. R. Spicer (HSO)
D. G. Wilson, D.I.M.A. (HSO)
R. J. Tanner (Senior Driving Examiner)
Miss J. M. Kemp, B.Sc. (SO)
Mrs S. Knapman, B.Sc. (SO)
G. R. Watts, B.Sc., Grad.Inst.P. (SO)

15.4.4 Vehicles Section

R. D. Lister, B.Sc., Assoc.Eng., C.E.ng., MI.Mech.E. (Head of Section)

A. W. Christie, B.Sc., M.A. (PSO)
E. O. C. Grattan, B.A., M.B., B.Ch., F.R.C.S. (PSO)
V. J. Jehu, B.Sc., M.Sc., M.Inst.P. (PSO)
Miss N. G. Clegg, M.A., M.B., B.Ch., M.R.C.S., L.R.C.P. (SSO)
J. Harris, C.Eng., A.F.R.Ae.S. (SSO)
R. N. Kemp, C.Eng., A.F.R.Ae.S. (SSO)
I. B. Laker (SSO)
F. T. W. Lander (SSO)
R. W. Lowne, B.Sc., M.Inst.P. (SSO)
G. N. Lupton, M.Inst.P. (SSO)
L. C. Pearson (SSO)
B. S. Riley, B.Sc., D.C.Ae. (SSO)
R. D. Stone, B.Sc. (SSO)
J. G. Wall, B.Sc. (SSO)
T. Williams, C.Eng., A.F.R.Ae.S., A.M.Inst.H.E. (SSO)
C. Blamey (HSO)
B. P. Chinn (HSO)
B. N. Farr (HSO)
J. A. Hobbs (HSO)
K. E. Holmes, C.Eng., M.I.Mech.E (HSO)
E. S. Lawrence, C.Eng., M.I.Mech.E., A.M.I.M.I. (HSO)
J. Masters (HSO)
G. Brock (SO)
R. G. T. Crisp (SO)
G. L. Donne (SO)
E. C. Field (SO)
J. K. Meades (SO)
P. M. F. Watson, C.Eng., M.I.Mech.E., M.I.Prod.E., A.M.B.I.M. (ENG.I)

15.5 TRANSPORTATION DIVISION

J. W. Fitchie, B.Sc., Ph.D., C.Eng., M.I.Mech.E., M.S.A.E. (Head of Division)
Personal Secretary: Miss I. H. Gilmour

15.5.1 TRAG

M. H. L. Waters,[1] B.Sc., Ph.D., C.Eng., A.F.R.Ae.S. (Head of Section)

J. A. Bunce, B.Sc., M.Sc., D.L.C., C.Eng., M.I.C.E. (PSO)
R. J. Balcombe, M.A., Ph.D. (PSO)
B. E. Grant,[1] B.Sc., M.Sc., C.Eng., A.M.I.E.E., A.F.R.Ae.S., M.I.E.R.E., M.S.E.E. (PSO)
R. J. Garvey,[2] B.Sc. (PSO)
C. G. B. Mitchell,[1] B.A., D.C.Ae., C.Eng., A.F.R.Ae.S. (PSO)
A. Naysmith,[1] B.Sc. (PSO)
J. Porter, B.Sc., M.Sc., C.Eng. (PSO)
T. R. Walsh,[3] B.Sc., A.C.G.I. (PSO)
J. K. Welsby,[5] B.A., M.Sc. (Econ. Adviser)
R. D. Andrews, B.Sc., M.Sc., Ph.D., A.K.C., A.F.I.M.A. (SSO)
D. A. Walmsley, B.Sc., Ph.D., A.M.Inst.P. (SSO)
J. Gray,[4] M.I.Mech.E. (P. & T.O.I.)
B. J. Searle, B.Sc. (HSO)
E. Akehurst, B.Sc., A.M.I.C.E. (SO)
V. P. Cook B.Sc., A.R.C.S. (SO)
H. Ellam, B.Sc. (SO)
D. J. Rutherford, B.Sc. (SO)
Miss J. Sherlock, B.Soc.Sc. (SO)
R. L. Williams, B.Sc. (SO)

Notes

1 Seconded from RAE Farnborough
2 Seconded from MOD (PE)
3 Seconded from Science Research Council
4 Seconded from Atomic Energy Authority (AWRE)
5 Seconded from DOE Headquarters.

15.5.2 Urban Transport Planning Section

A. R. Cawthorne, B.Sc., C.Eng., A.F.R.Ae.S. (Head of Section)

J. D. Downes, B.Sc. (PSO)
A. J. Harris, B.Sc. (PSO)
E. M. Holroyd, B.Sc. (PSO)
R. L. Moore, O.B.E., B.Sc., M.Sc., M.Inst.P. (Dis-PSO)
J. C. Tanner, M.A., F.S.S. (PSO)
M. R. Wigan, M.A., D.Phil., M.Inst.P., M.O.R.S.A., F.S.S., M.B.C.S. (PSO)
Miss J. E. Beardwood, B.A. (SSO)
L. Gyenes, B.Sc. (SSO)
D. A. Lynam, B.Sc., M.I.C.E. (SSO)
A. H. Tulpule, B.Sc., M.Sc., M.A., B.Litt. (SSO)
J. W. Tyler, Dip.Stats. (SSO)
R. L. Watson, B.Sc. (SSO)
J. Northrop, D.S.O., D.F.C., A.F.C. (HSO)
T. J. G. Bamford, B.Sc. (SO)
S. T. Divey, B.Sc. (SO)
Miss E. B. Duplantier, B.Sc. (SO)
J. F. Lindsay, B.Sc. (SO)
S. V. Magee, B.Sc., Grad.I.M.A. (SO)
P. J. F. Millier, B.Sc. (SO)
N. J. Paulley, B.Sc. (SO)
Miss B. A. Thomas (SO)
D. Wanless, B.Sc., M.Sc. (SO)

15.5.3 Environment and Freight Section

L. H. Watkins, B.Sc., C.Eng., M.I.C.E., M.Inst.H.E., F.R.Met.S. (Head of Section)

R. F. F. Dawson, B.A., F.S.S. (PSO)
D. Fiddes, B.Sc., M.Sc., D.I.C., C.Eng., M.I.C.E. (PSO)
D. G. Harland, B.Sc., M.Inst.P. (PSO)
D. M. Colwill, B.Sc. (SSO)
L. E. Hogbin (SSO)
J. A. Forsgate, B.Sc. (HSO)
P. A. K. Greening, B.Sc. (HSO)
A. O. Grigg, Dip.Tech. (HSO)
N. F. Ross, B.Sc. (HSO)
M. G. Bevan (SO)
M. Cheesman, B.Sc. (SO)
W. G. Ford (SO)
L. J. Griffin, B.Sc. (SO)
A. J. Hickman, B.Sc. (SO)
P. M. Nelson, B.Sc. (SO)
M. C. R. Underwood, B.Sc. (SO)

15.6 ADMINISTRATION AND SERVICES DIVISION

15.6.1 Technical Services

Information

R. R. Boyce, M.I.P.R. (PIO) (Head of Information Services)
Mrs P. E. Mongar, B.Sc., M.I.Inf.Sc. (PSO)
G. B. Taylor, B.Sc. (SSO)
P. A. Chapman (HSO)
Mrs B. A. Crofts, B.A. (HSO)
C. O. Fraser, M.I.L. (HSO)
M. Harvey, A.C.I.S. (HSO)
S. G. Jobbins (HSO)
Mrs J. M. Macnaughtan (HSO)
Mrs S. E. Taylor (HSO)
A. D. Caswell, B.Sc. (SO)
Mrs P. Ferne, B.Sc. (SO)
N. L. Scott, B.Sc. (SO)
F. W. Avann (SIO)
R. P. Kent, M.Inst.M.S.M. (IO)
I. M. Paterson (IO)
L. A. J. Booker, B.E.M. (AIO)
S. N. Shead (AIO)
Miss D. M. Bowden (Exec.O)

Organization

E. H. Morgan (S.Exec.O)
Mrs S. MacDonald, B.A. (Exec.O)
R. W. T. Macey (Exec.O)
Mrs G. J. Rogers (Exec.O)

Photographic

F. H. Stokes (C.Photo.)
R. H. Burrows, A.M.I.R.T. (P.Photo.)
A. E. Daniels, A.R.P.S., M.B.K.S. (P.Photo.)
W. G. Heath (P.Photo.)
R. J. P. Owen (P.Photo.)
K. A. Parker, M.B.K.S. (P.Photo.)
S. F. Campbell (S.Photo.)
C. N. Durley (S.Photo.)
J. H. Ferguson (S.Photo.)
P. Gillett (S.Photo.)
S. J. Humphrey, M.B.K.S. (S.Photo.)
Miss A. Lumley (S.Photo.)
D. L. Moseley, M.B.K.S. (S.Photo.)
R. H. Palmer, A.I.I.P. (S.Photo.)
F. T. G. Pond (S.Photo.)
J. Williamson (S.Photo.)

Courses and Training

C. J. Godfrey, B.Sc., C.Eng., M.I.C.E., M.Inst.H.E., A.M.I.P.M., F.R.S.A. (SEO)

15.6.2 Engineering Services

T. Barrett, B.Sc., C.Eng., M.I.Mech.E. (Head of Engineering Services)

Civil Engineering

J. A. Chappell, C.Eng., F.I.Struct.E., M.Inst.H.E. (PSO)
E. N. Bancroft (SSO)
G. C. Williams (SO)
F. W. L. Shepard, M.B.E., B.Sc., F.I.C.E., M.I.Mech.E., M.Inst.Pet. (MGE)
E. Francis (TWO II)

Experimental Equipment Design

F. G. Taylor, C.Eng., M.I.Mech.E. (PSO)
Miss A. L. Abbott (HSO)
C. H. Davies (HSO)
A. H. Smith, M.Inst.B.E. (HSO)
I. F. A. Wickens, M.I.E.D. (HSO)
D. T. E. Rutledge, C.Eng., M.I.Mech.E., A.M.Inst.E., A.M.Inst.H.E. (MGE)
S. Swinney, C.Eng., M.I.Mech.E., M.Inst.H.E. (MGE)
B. A. Mecklenburgh (BGE)

Accommodation and General

N. T. Cox (SSO)

Fire and Safety

G. E. Eaton, F.B.I.C.C., M.R.S.H., A.I.I.S.O. (HSO)

Workshops and Transport

D. A. Smyth, C.Eng., M.I.Mech.E., M.I.Prod.E. (MGE)
D. W. Holland (TWO I)
E. J. Burt (TWO II)
J. C. T. Richards, C.Eng., M.I.E.R.E. (TWO II)
R. Soanes (TWO II)

15.6.3 Executive Services

H. C. Thorner (Principal) (Head of Executive Services)
E. P. Jennings (S.Exec.O)
J. Allan-Jones (H.Exec.O)
L. W. Hinrich (H.Exec.O)
*W. J. Louch (H.Exec.O)
A. D. Marshall (H.Exec.O)
A. Walker (H.Exec.O)
*G. W. C. Felton (Exec.O)
E. A. Jones (Exec.O)
B. King (Exec.O)
Mrs V. S. D. Lycett (Sen.Pers.Sec.) (Directorate Services)
Miss M. A. Masters (Exec.O)
T. F. Morgan (Exec.O)
Miss N. B. Mossman (Exec.O)
A. J. Shaw (Exec.O)
Miss D. C. M. Shepherd (Exec.O)
W. Wainwright (Exec.O)
D. Welford (Exec.O)
A. East, M.V.O. (S.Security O)

*On temporary promotion

PREFIXES

Multiples and submultiples of the basic metric units are formed by means of prefixes. These prefixes are:

Prefix	Symbol	Factor by which the basic unit is multiplied
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
	Basic unit	10^{0}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

CONVERSION TABLE

Length								
0·039	in	=	mm	1	in	=	25·4	mm
3·281	ft	=	m	1	ft	=	0·305	m
0·621	mile	=	km	1	mile	=	1·609	km
Area								
0·0015	in^2	=	mm^2	1	in^2	=	645·2	mm^2
10·76	ft^2	=	m^2	1	ft^2	=	0·093	m^2
0·386	$mile^2$	=	km^2	1	$mile^2$	=	2·59	km^2
2·47	acre	=	ha	1	acre	=	0·405	ha
Volume								
0·061	in^3	=	cm^3	1	in^3	=	16·39	cm^3
0·0353	ft^3	=	litre (dm^3)	1	ft^3	=	28·32	litre (dm^3)
1·31	yd^3	=	m^3	1	yd^3	=	0·765	m^3
Capacity								
0·22	gal	=	litre	1	gal	=	4·55	litre
Mass								
0·035	oz	=	g	1	oz	=	28·35	g
2·2	lb	=	kg	1	lb	=	0·454	kg
				1	cwt	=	50·8	kg
0·984	ton	=	Mg	1	ton	=	1·016	Mg
Volume rate of flow								
35·3	cusec (ft^3/s)	=	m^3/s	1	cusec (ft^3/s)	=	0·028	m^3/s
Density								
0·0361	lb/in^3	=	g/cm^3	1	lb/in^3	=	27·68	g/cm^3
0·0624	lb/ft^3	=	kg/m^3	1	lb/ft^3	=	16·02	kg/m^3
0·752	ton/yd^3	=	Mg/m^3	1	ton/yd^3	=	1·329	Mg/m^3
Force								
0·225	lbf	=	N	1	lbf	=	4·45	N
0·100	tonf	=	kN	1	tonf	=	9·96	kN
100	tonf	=	MN	2				
Pressure/Stress								
0·145	lbf/in^2	=	kN/m^2	1	lbf/in^2	=	6·894	kN/m^2
0·021	lbf/ft^2	=	N/m^2	1	lbf/ft^2	=	47·88	N/m^2
145·0	lbf/in^2	=	NM/m^2	1	$tonf/in^2$	=	15·44	MN/m^2
20·9	lbf/ft^2	=	kN/m^2	1	$tonf/ft^2$	=	107·25	kN/m^2
			Note: N/mm^2 and MN/m^2 are numerically equal					
Velocity								
3·281	ft/s	=	m/s	1	ft/s	=	0·305	m/s
0·621	mile/h	=	km/h	1	mile/h	=	1·609	km/h
Temperature								
$\left(\frac{9}{5}\times +32\right)$	°F	=	°C	×	°F	=	$\frac{5}{9}\left(\times -32\right)$	°C
Plane angle								
57·296	degree (°)	=	rad	1	degree (°)	=	0·0175	rad
Frequency								
			Note: This SI unit for frequency is the Hertz (Hz) 1 cycle per second (1 c/s) = 1 Hz					
Fuel consumption								
2·83	mile/gal	=	km/1	1	mile/gal	=	0·354	km/1

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