ROAD RESEARCH LABORATORY

Ministry of Transport

RRL REPORT LR 243

# RESEARCH ON PAVEMENT DESIGN

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Crowthorne, Berkshire
1969

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ABSTRACT

The basis of the structural design of road pavements in Britain is reviewed and compared with the design procedures used for other structures.

The need is stated for a method of pavement design based upon permissible stresses in the various layers which will limit the deformation or cracking to acceptable levels under given numbers of vehicles of various weights.

The preparation of such a method requires several major fields of research to be brought to an adequate stage at about the same time. The RRL research programme in these fields is outlined.

## 1. INTRODUCTION

Current expenditure on new roads and major improvements in the United Kingdom is about £270 million per annum, and about one-third of this is on the pavement itself. To this must be added a somewhat larger proportion of the £35 million per annum on housing estate roads, and a somewhat smaller proportion of the £140 million per annum on maintenance and minor improvements, which includes strengthening existing pavements. Thus each 1 per cent improvement in design efficiency will give a return of one to two million pounds per annum, and the possibility of such improvements merits serious investigation.

The pavement designs given in Road Note No.29[1] are based mainly on the performance of full-scale experimental pavements subjected to actual traffic and environmental conditions for periods up to 20 years or so. This basis gives sound designs that give satisfactory service for many years, but has a number of disadvantages. It takes many years to lay a full-scale experiment and observe it for long enough to demonstrate that a new material or design feature is satisfactory for general use. Also, although the experimental results are supported by an increasing understanding of the vehicle loadings and the behaviour of the roadmaking materials as a result of research in the last 10 to 15 years aimed at improved methods of pavement design, this understanding is not yet precise enough to give the necessary guidance on the way in which materials and structural design might be substantially improved.

These difficulties could be overcome, and other benefits obtained, when research has progressed sufficiently to allow the use of design methods similar to those used for aeronautical and for many civil engineering structures. In these methods a knowledge of the applied loading and the geometry of the structure is used to calculate the working stresses in the structure and these are compared with permissible values for the materials concerned, usually with some safety factor. If doubt exists strength tests are made to an accelerated time scale.

The application of such methods to pavements is in some respects more difficult than to other structures, and requires further advances in knowledge of vehicle loadings, structural theory and testing, material properties, etc. The purpose of this report is to discuss these requirements with particular reference to the relevant aspects of the programme of research at the R.R.L., the aim of which is to bring the results of several lines of research together in an improved method of pavement design in 4 to 5 years time, although the research will provide valuable interim improvements meanwhile.

## 2. BASIS OF PRESENT DESIGNS

Road Note No.29 was introduced in 1960 and revised in 1965. Traffic is specified as the number of commercial vehicles (i.e. over 1,524 kg (30 cwt) unladen) per day in both directions, or on both carriageways if dual, expected on the road 20 years after construction. A traffic growth rate of 4 per cent per annum for major through roads is recommended if better estimates are not available. Pavement designs are given for traffic categories covering the range from lightly trafficked housing estate roads to heavily trafficked trunk roads or motorways.

For flexible construction the thickness of the wearing course, basecourse and base depend upon the traffic category and the broad class of material to be used (e.g. rolled asphalt, bitumen macadam, tarmacadam, lean concrete or wet-mix macadam). The thickness of the sub-base depends on the California Bearing Ratio of the subgrade, subject to a minimum thickness when the subgrade is susceptible to frost. The CBR value may be obtained from tests on remoulded samples of the soil, or estimated from a knowledge of the soil type and expected drainage conditions.

For rigid construction the thickness of the concrete slab and of the base both depend on the traffic category and on the subgrade condition (very stable, normal, or very susceptible to non-uniform movement).

The thicknesses of the various layers for both flexible and concrete construction are mainly derived from the performance of full-scale experimental pavements constructed to the designs of the RRL. The experiments, usually comprising numerous sections each about 60m long, are laid as part of a new road construction and subjected to actual traffic loadings and environmental conditions for periods up to 20 years or more. The sections include various materials and thicknesses of base and surfacing in flexible construction, or of slab thickness, reinforcement and joint design in concrete construction. The composition and laying of the materials are carefully controlled and the material properties measured as far as practicable by non-destructive tests in situ, and by taking cores for laboratory tests, both during construction and during the life of the experiment. Other measurements include the permanent vertical deformation of the surface for flexible pavements, and measurements of the lengths of cracks of various widths in concrete pavements. The transient vertical deflection of the pavement under a standard wheel load is measured at intervals by the deflection beam and at the more important sites the traffic volume and weight are sampled regularly with an electronic weighbridge installed in the nearside lane. Stress and strain measurements are made at some sites. A list of pavement design experiments laid since 1945 is given in Ref. 2 with a brief indication of their purpose and present status. Further details are given in Refs. 3 to 11.

These full-scale experiments have given, and will continue to give for years to come, a wealth of factual data on the performance of pavements built to British specifications with representative materials and equipment on typical soils, and subjected to the correct loading and climatic conditions. These data could not have been obtained in any other way and are essential to our present knowledge of how to build sound pavements in a variety of materials.

The full scale pavement design experiments suffer, however, from a number of drawbacks:-

(i) *The time taken to get results* Details of the experimental lengths must be included in the tender documents so that the costs additional to the standard construction for the relevant length of road are included in the contract price. For a major experiment this means that the experiment may be designed two or three years before the sections are completed and opened to traffic. Thereafter several years may elapse before useful results are obtained. In some cases the construction may be 'under-designed' to accelerate failure, and in others the relative rates of deformation may give valuable comparisons long before failure occurs, but naturally most value comes from a knowledge of the useful life of pavements of normal construction and this, by definition, requires up to 20 years. A more rapid method is needed to demonstrate that new materials or forms of construction are satisfactory for general use.

(ii) *The empirical nature of the results* The sections in the full-scale experiments, although numerous, do not include all the combinations of material, thickness, environmental conditions, etc., of interest. A method is needed to complete and extend the information obtained from the full-scale experiments.

(iii) *Their cost* The Alconbury Hill experiment cost about £100,000 to lay in excess of normal cost for a road of this type and requires about £1,000 per annum for observation and repairs.

The experimental results have of course been supplemented by a vast experience of practical road-building, and by a general engineering understanding of the properties of roadmaking materials and the structural function of the pavement. In recent years the latter has been helped by a growing ability to calculate and measure stresses and strains in road pavements and to measure relevant material properties. The present position of research in these fields is sumarised in Section 5 and references given to the more important papers. These developments are already playing a part in selecting improved designs but have not led to a comprehensive theoretical framework or model with adequate data on materials, etc., and to a method of testing in an accelerated time-scale, with the ability to

(a) specify the combinations of material and thickness for each layer of the pavement to give the minimum cost, for the specified service conditions

(b) take proper account of changes in vehicle loadings (e.g. the introduction of heavier axle-loads) or other service conditions

(c) indicate the most important properties of road-making materials, and hence the most fruitful lines of research

(d) investigate the value of novel forms of construction

(e) take full advantage of reduced variability in the properties of materials

(f) validate improvements in materials and design without lengthy field experiments.

The procedure in other branches of structural engineering which have reached such a stage is described briefly in the following section.

## 3. PRACTICE IN OTHER FIELDS

The design and validation procedure for the strength of civil and aeronautical structures may broadly be described as:-

(i) Specification of the functional and other requirements for the structure including the required period of use.

(ii) Specification and calculation of the consequent loads to be applied to the structure. The loads may include both 'internal' loads (e.g. the weight of the structure itself, the weight of contents, internal pressures) and 'external' loads (e.g. aerodynamic forces, impact forces). The loads may be specified directly (e.g. a force per unit area) or indirectly (e.g. a wind velocity).

(iii) Specification of the relevant environmental conditions (e.g. temperature).

(iv) Specification of safety factors by which the loads are to be multiplied.

(v) Calculation by approved methods of the distribution of the loads within the structure and of the resulting stresses.

(vi) Specification of the maximum stresses permissible in various materials and in various circumstances, and comparison with the calculated stresses to check that the specified safety factors are achieved.

The permissible stresses are usually obtained by laboratory tests on small specimens or structural details and partly from analysis of service experience of similar structures. The values of the applied loads and the safety factors are obtained partly from experience and from calculation and measurement of the forces that can arise, and partly from estimation of the uncertainties in load estimation, material properties, stress calculation, construction processes and deterioration in service. Various combinations of design load, calculation method, permissible stress and safety factor can load to virtually the same structure, and to some extent therefore the choice of the numbers is arbitrary. The present 'rational' trend is, however, to make each of the quantities as accurate as possible. Attention is being concentrated on 'limit state design' in which various undesirable limit states (e.g. excessive deformation, collapse) are identified and a length of time specified during which the structure should be free from each defect. Loads of a magnitude likely to arise in this length of time are selected and the structure when subjected to these loads, must be free from the defect, possibly when the material properties are arbitrarily reduced to allow for possible deterioration in service, or other defects or uncertainties.

Many new designs of structure are approved on the basis of strength calculations only. For complex structures, or those with novel features, the strength calculations may be supplemented by tests of model or full-scale structures during design and development, and the load and stress calculations checked later by measurements on the structure in use. For new aircraft one or two complete airframes are commonly provided for static and fatigue strength tests.

## 4. APPLICATION OF IMPROVED METHODS OF PAVEMENT DESIGN

Before considering the problems involved in providing an improved method of pavement design it is worth comparing the structural requirements of a road pavement with those of an aircraft, a building or a bridge. The main difference is probably that structural safety (i.e. the prevention of structural collapse) is not usually a problem for the pavement. However operational aspects of safety are present (e.g. danger to vehicles caused by water in wheel tracks) and generally the limit to surface deformation set by this requirement will be critical before structural break-up of any consequence occurs. Limits to surface deformation may also be set by vehicle response which affects the comfort of drivers and passengers and also the dynamic loads applied to the pavement. The need for safety factors therefore does not arise for pavements. The problem is to provide an economic design that will be serviceable (defined in terms of limiting deformation or cracking) for a certain period, and this is very similar to the corresponding requirements for other structures.

There could be many variants of improved methods of pavement design. For the purpose of this discussion the essential features would be:

(i) a specification of vehicle loading

(ii) a specification of environmental conditions, particularly temperature and moisture

(iii) a means of calculating the stresses and strains caused by the traffic, which implies adequate theory and a knowledge of the relevant material properties

(iv) a knowledge of the permissible stress or strain levels for various materials i.e. the values which, when repeated a large number of times under the appropriate environmental conditions, just keep the deformation or cracking of the pavement within the limiting values

(v) previous demonstration that (i) to (iv) can be used to predict the service behaviour of a pavement and

(vi) preferably an accelerated-time method of testing the performance of a complete pavement under laboratory conditions.

The procedure that would be involved is shown diagrammatically in Figs. 1 and 2. In Fig. 1 it is assumed that an initial estimate of the thickness of the various layers of the pavement has been made. The stresses and strains caused by the traffic are calculated by elastic theory and the deformation and cracking caused by their repeated application computed. The deformation and cracking are then compared with the permissible values, and, if different, the thicknesses of the layers are altered to suit. The unit cost data are used to compute the cost of the design, and alternatives compared in a search for the cheapest. Comparison of computed deformation, cracking and deflection can be made with test results when available.

Fig. 2 represents a more advanced stage of development in which the thicknesses of the various layers are not assumed initially, but are calculated by computer, using the unit materials costs, to give the cheapest design.

The required material properties, and the main variables on which they depend, are indicated in the following table:

**TABLE I**

| MATERIAL | PROPERTY | VARIABLES |
|---|---|---|
| Soil | Dynamic Modulus<br>Poisson's Ratio<br>Deformation against number of applications for various combinations of vertical stress and deviator stress | Soil type<br>Compaction<br>Moisture conditions<br>Loading history |
| Unbound base and sub-base materials | As above | Aggregate<br>Compaction<br>Moisture conditions<br>Loading history |
| Bituminous-bound materials | Dynamic Modulus<br>Poisson's Ratio<br>Deformation against number of applications of various vertical stress levels<br>Tensile/flexural cracking against numbers of applications of various stress levels | Aggregate<br>Binder<br>Temperature<br>Loading rate<br>Loading history |
| Cement bound materials | Dynamic Modulus<br>Poisson's Ratio<br>Tensile/flexural cracking against number of applications of various stress levels | Aggregate<br>Cement content<br>Density<br>Loading history |

The improved method will rely heavily on theoretical work and laboratory measurements, but these aspects will supplement rather than supplant data from full-scale experiments. Some of the experiments now laid will give valuable results for a decade or two to come, and these results are needed for the development and validation of the improved methods in addition to their more traditional use. Some change in emphasis from field work to laboratory work is, however, to be expected and further full-scale experiments may change in character, perhaps away from the Alconbury/Wheatley By-pass pattern to detailed observation of representative lengths of non-experimental construction, and experiments on means of strengthening existing pavements (See Section 6).

The economic returns from the development of such a method cannot be assessed numerically with any confidence. The combinations of conventional materials and thickness included in the full-scale experiments, although numerous, are not comprehensive. The gains to come from other combinations of existing materials may be modest, although large enough alone to justify the research. The major gains are more likely to come from more radical improvements in materials and structural design, speed of application, and ability to re-design with confidence in changing circumstances. Indeed it may well be that major gains in these directions will only come from basic improvements in analytical, design and testing techniques.

The application of rational design methods to road pavements is in some respects more difficult than for most engineering structures. The latter, mainly made of metals or concrete, behave for all practical purposes linearly with load in the range of working loads, and their properties are effectively insensitive to temperature. Bituminous roadmaking materials on the other hand are visco-elastic in their range of working load, and their strength and stiffness are sensitive to the range of temperature and rate of application of load that occurs. There are numerous specifications for bound and unbound roadmaking materials (although an attempt is being made to reduce the number) and a wide range of properties can occur within the limits of a single specification. As the materials are largely natural or waste materials produced in large quantities at a low price the variability in material properties is larger than that of the metals. The loading, and the consequent mode of failure, is repetitious, and this has to be considered from the start. Many other structures, although subject to repeated loadings and in principal subject to the risk of fatigue, can be designed largely on a 'static load' basis and possibly checked for fatigue later. Also pavements involve the structural behaviour of soils and unbound granular materials under repeated loading. Some of these are sensitive to moisture conditions and present problems absent in most structures. From the theoretical aspect the pavement is more difficult than many apparently more complex structures.

In one respect however the pavement has an advantage over most other structures where limit state design is concerned. Most structures fortunately fail very rarely and it is therefore difficult in many cases to specify what defects constitute unserviceability and what level of load should be applied before they occur. At least it can be said of road surfaces that examples of failure are not difficult to find, although the allocation of the contribution to the failure by the various layers of the pavement, and the mechanisms by which such failures develop, is more difficult.

## 5. PROGRAMME OF RESEARCH

Research aimed generally at improved methods of pavement design has been in progress at the RRL for several years.[12] This research has already contributed much to the general understanding of the structural behaviour of roadmaking material and pavements. At present a number of lines of research are in progress with the aim of bringing them together in four or five years time to provide a method of the type described above. The remainder of this Section describes these lines of research.

## 5.1 Loading

The loading of consequence to pavements[13] is that applied by a succession of single wheels (including two tyres mounted a foot or so apart as a single wheel – or 'half-axle'). Other wheels even as little as 1m away are thought to have little effect, although this remains to be checked in detail. The important characteristics are the numbers of wheel loads and, particularly, their magnitude. The AASHO tests[14] showed that the 'damaging power' of a wheel-load varies approximately with the fourth power of its magnitude. For this reason only heavy commercial vehicles are of concern for pavement structural design. For a given number of wheel loads having a certain distribution of load magnitudes (or load spectrum) this knowledge can be used to calculate the equivalent number of wheel loads of a standard magnitude (commonly taken as 40kN (9000 lbf)) which cause the same damage to the pavement. This gives a convenient simple indication of the general severity of the load spectrum. The applicability of the AASHO factors to British conditions needs varification, and some work to this end is proceeding in Road Machine No. 3.

In this country wheel load spectra have been recorded by electronic weighbridges at the major experimental sites for some years[15,16] and a weighbridge has recently been installed in the southbound carriageway of M1. The spectra vary with the type of road and in some cases with the direction of the traffic. Wheel loads exceeding the legal maxima occur and do a substantial part of the damage.

The dynamic load applied to the road depends on the vehicle weight and on the impact factors due to the interaction between irregularities on the road surface and the vehicle suspension. Vehicle responses to various surface irregularities are being studied both theoretically and experimentally,[17,18,19] and in the near future it should be possible to estimate impact factors for all types of commercial vehicle in common use.

For pavement design purposes a standard wheel-load spectrum (or possibly a small number of spectra varying in severity with e.g. the type or location of the road) will be needed to associate with the forecast number of commercial vehicles for the new road. Similar data are needed for the design of highway bridges, although the bridge problem is more difficult because more detailed traffic data are needed, and design lives are longer, thus requiring more extrapolation into the future.

The measurement of wheel-load spectra in future will be simplified by the use of a load-measuring mat developed at the RRL. This is attached to the surface of the road and is therefore much quicker and cheaper than the present weighbridge which requires the construction of a pit in the road. It may be possible to take regular samples of wheel-load spectra at some of the census points used regularly for vehicle counts.

## 5.2 Temperature Variations

Temperatures are important to the structural performance of pavements, in addition to the particular problems caused by frost. High temperatures have an adverse effect on the structural properties of bituminous materials. The ranges of temperature, and the consequent changes in dimensions, dominate joint design and induce thermal stresses in concrete pavements.

A method is needed to calculate the temperature-depth-time relationship in various pavement structures from a knowledge of the important climatic factors for the region concerned, such as radiation and ambient air temperature. This information could possibly be presented in the form of a standard annual cycle of temperature variation, with superimposed diurnal cycles. Some correlation between temperature spectra and wheel load spectra will also be needed.

Certain temperature data for road slabs[20, 21] and temperature design data for bridges are already available.

Research will continue with the aims of:-

(a) determining which climatic conditions should be considered in pavement design and

(b) deriving a satisfactory method of calculating the resulting temperatures in the pavement.

## 5.3 Structural theory

The ability to calculate the stresses and strains caused in a multi-layer pavement by a given wheel-load is essential to improved methods of pavement design. To do this one must have the relevant structural equations and the means of solving them, and the relevant material properties to feed into the equations. This section is concerned with the equations and their solution. The derivation of material properties is discussed in Section 5.4.

The equations giving the stress, strain and deflection of a multi-layered structure overlying a semi-infinite solid, caused by a static applied load, all materials being assumed elastic, have been available for some years, together with solutions for 2 and 3 layer cases[22, 23, 24]. A computer programme is now available at RRL to give on-axis solutions for any number of layers[25], and is to be extended to give off-axis solutions. A programme is also being prepared to give the 'single-layer equivalent' of a multi-layer pavement (i.e. one which gives the same stress on the subgrade for the same wheel-load) as an aid to optimisation of pavement design.

Low priority is being given to visco-elastic theory as it is believed that the first rational method of pavement design will be based on elastic theory using suitable 'quasi-static' material properties, and in view of the considerable effort being devoted elsewhere[26] to visco-elastic theory

For concrete pavements the theory relating to traffic loading needs extending to include stresses due to thermal effects.

## 5.4 Comparison of theory and experiment

It has been shown that no significant errors are introduced by representing the actual shape and pressure distribution of the contact area of a loaded tyre by a uniformly loaded circular area[27,28]

It has also been shown that, if the materials behave elastically, the instantaneous stress and strain distribution caused by a wheel moving at vehicle speeds over a smooth surface is virtually the same as that caused by the same wheel when stationery.

However, many roadmaking materials are visco-elastic, and their elastic properties change with temperature, rate of loading and loading history. Two problems arise in the use of elastic theory with such materials, first that of obtaining the 'quasi-elastic' properties for the appropriate rates of loading and over the appropriate range of temperature, including possible changes during the service life of a pavement; and second that of checking whether or not such 'quasi-elastic' properties when used in conjunction with elastic theory do give estimates of stress and strain sufficiently accurate for practical design purposes.

Values of Young's Modulus and Poisson's Ratio have been measured for various road-making materials both in actual roads and in the laboratory. These values have been used in conjunction with elastic theory to calculate stresses and strains in various pavements for comparison with measured values. The present indications are that adequate estimates can be made with elastic theory although further verification is needed, and that the main problem is that of establishing suitable 'quasi-elastic' properties for the range of materials and conditions, allowing for the variability of the materials[29].

A systematic check on the applicability of elastic theory will be made in the Pilot Scale Building at Crowthorne. Two soils are being used, a sand and a clay. So far, the subgrades have been laid and are instrumented to measure soil pressure and strain in all directions, and also vertical deflection. Measurements will be made using various forms of loading after which the tests will be repeated with the loads applied via a surface layer laid directly on top of the soil. A concrete layer of known elastic modulus will be laid first and this is likely to be followed by an asphalt layer. The surfacings will be changed without disturbing the soil beds and the instruments. The validity of the elastic theory will be assessed by comparing the measured and calculated values of stress, strain and deflection.

Measurements of dynamic modulus, stress, strain and deflection will be made in sections of the full-scale experiment on A1 at Conington Lodge, Hunts, and will provide comparisons of calculated and measured values. It is also expected that the laboratory tests of materials under repeated loading (see Section 5.6 (a)) will show how Young's Modulus changes with load history.

### 5.5 Permissible stresses – full-scale experiments

By permissible stress is meant the stress (or stress spectrum) that a roadmaking material or soil can withstand the required number of times without exceeding some specified limit of deformation (due to compaction or flow) or cracking, or possibly loss of elastic modulus. The design criterion clearly has to be met by the pavement and subgrade as a whole, and each layer has to be kept within its own limits in order to meet the overall criterion.

Knowledge of material properties comes from two sources (1) tests on materials in the laboratory (discussed in 5.6) and (2) analysis of the numbers of various stresses that materials have withstood in the RRL full scale experiments. This analysis, which is the reverse of the proposed design method, would involve taking a section from a full-scale experiment for which would be known :

(a) the materials and thickness of the various layers

(b) some measurement or estimate of their Young's Modulus and Poisson's Ratio, possibly changing with time

(c) the annual traffic in terms of commercial vehicles, and the wheel load spectrum, allowing conversion to the equivalent number of standard wheel loads

(d) the increase in surface deformation with time, and records of any cracking

(e) possibly measurements with the deflection beam, measurements of stress and strain, and location of failing areas by wave propagation techniques.

The elastic theory and elastic properties of the materials can be used to calculate the stresses and strains caused at critical locations in the surfacing, base, sub-base and subgrade by a standard wheel-load, and checked against measurements if available. The theoretical surface deflection can also be calculated to check against the deflection beam value, if available. For each layer it may therefore be possible to say that its performance was satisfactory or otherwise when subjected to a certain number of applications of certain stresses and strains. It may not always be possible to identify for each layer the boundary between satisfactory and unsatisfactory performance, because the contribution of each layer to the performance of the complete pavement may not be known, but it should be possible to build up a general quantitative knowledge of material performance under repeated loading in situ to compare with the laboratory tests.

It is planned to make a major review of this work in about 1970. By this time the Alconbury Hill experiment will have run for over 12 years and will be the main source of data. Several smaller experiments will also contribute and at least some indications should be available from Alconbury and Wheatley By-passes.

## 5.6 Permissible stresses – laboratory tests

(a) *Bound materials*

Both concrete and bituminous materials tend to form 'fatigue' cracks when subjected to repeated loading. For concrete road pavements the length and width of cracking is the main criterion of failure. The importance of fatigue cracking in bituminous materials is less clear. Cracks are known to occur under repeated loading and may be accompanied by a reduction in Young's Modulus, which would tend to overload the other layers of the pavement, but cracks are also known to 'heal' during rest periods, particularly under a suitable stress.

In the laboratory, specimens of materials can be tested quickly over a systematic range of controlled conditions. The stresses induced in simple beams are less complex than those in actual pavements, but if some correlation can be established between critical conditions in a laboratory test and conditions in a full-scale experiment, results from future laboratory tests could be used with confidence to derive permissible design stresses, and to develop improved materials.

The RRL is therefore setting up a fatigue laboratory which will be equipped with seven electro-hydraulic machines capable of applying controlled load or displacement over a range of frequencies and waveforms, at controlled temperatures. These machines can be used for testing specimens of bitumen, tar and cement bound materials. A less complex mechanical machine is being made to test concrete beams.

Surveys of the present state of knowledge on the repeated loading of bituminous materials and of unreinforced concrete have been made[30, 31] and initial research programmes drafted to start to fill the major gaps in knowledge.

The initial work on bitumen-bound material is being concentrated on a thorough examination of the properties of one basecourse mix. This will allow later expansion to cover other mixes with maximum efficiency in the light of the information obtained from the first phase. The basecourse mix selected for this work has a composition roughly in the middle of those permitted by the specifications and is the mix used as a control or reference mix by Nottingham University in fatigue tests using cantilever specimens subjected to rotating bending. In the RRL tests, beam specimens will be subjected to four-point bending and the main objective in the initial phase will be to determine the life of test specimens under various loads considering the effect of:-

(i) the shape of the loading pulses

(ii) the rate of loading

(iii) rest periods between the loading pulses

(iv) the stress level and temperature of the material.

The programmes at Crowthorne and at Nottingham University are intended to be complementary. The latter employs sinusoidal loading and will study the effect on fatigue life of the parameters associated with the mix such as binder content, type of binder, type of aggregate, grading, fines content, etc. Because of the loading system employed at Nottingham it is unlikely that the results can be directly applied to pavement design, but they should indicate which of these parameters should be studied in greater detail by the Laboratory.

A complementary test programme is planned to study the fatigue behaviour of tar-bound materials at RRL both for comparison with the bituminous materials and in relation to Nottingham University's programme, which includes tar binders. The work on tar-bound material will start some months later than that on bitumen-bound material, but will benefit from the development of techniques and from the results obtained for the bituminous materials.

Where the cement-bound materials are concerned, a start is being made with a pavement quality concrete and the leaner materials, used as bases under bituminous surfacings, will be tackled later.

For plain concrete the initial emphasis will be on time-dependent parameters, such as specimen age, rate of loading, shape of load cycle, pulse loading and rest periods, all under constant amplitude loading. The programme will then be extended to cover stress interaction effects with particular emphasis on the assessment of cumulative fatigue damage under load histories approximating to traffic loads on highway pavements.

Attention is being concentrated initially on the effects of repeated loading on fatigue cracking and elastic modulus because these effects are more suitable for laboratory than field study. However the compaction (and possibly flow) of bituminous materials under repeated loading is known to be important. A programme of laboratory tests is being formulated to supplement the data on deformation of actual roads, and a large triaxial machine has been built for this purpose.

This programme of tests under repeated loading, in addition to providing data on the properties of present materials, will play a part in improving mix design, and will have to be closely co-ordinated with research on improved material specifications and methods of performance testing.

(b) *Unbound materials*

A small machine for tri-axial loading of specimens of soil was developed at RRL[32] and a series of exploratory tests made on a reconstituted clay. A batch of 9 such machines is now in action and will be used for a systematic examination of the effects of repeated loading on the deformation and stiffness of soils.

The object of this work will be primarily to relate these properties to the classification and pore pressure condition of the soil. Tests on heavy clays, silty and sandy clays and sands are planned.

Similar tests will be required on unbound sub-base and base materials. These tests have not been started and will need urgent attention to obtain results in the same time scale as the other aspects of the programme.

## 5.7 Pilot-scale tests

If a design method based on permissible stresses in each layer is established, there will still be a need, although not as great as at present, for a test on the complete pavement. The conventional full-scale experiment under traffic takes too long. The Road Machine No. 3 at Harmondsworth[33] applies about 3600 repetitions of load per 20 hour day, which is not more than a busy road, although in the Road Machine the use of a constant high load or temperature can, within limits, be used to accelerate the test. Higher rates of loading by devices with wheels, whether circular or linear, are difficult due to the high inertia forces. However, rates of loading of 1 cycle/sec (probably the highest that should be used for bituminous pavements) or even 10 cycles per second (probably acceptable for concrete) are easily achieved by hydraulic jacks.

The stress system induced in a pavement by a pulse from a jack is not the same as that caused by a moving wheel. It may however be possible to simulate the stress at selected critical positions with adequate accuracy. The Bundesanstaldt fur Strassenwegen[34] have obtained some correlation between the deformation of a pavement tested by impulsive loading in the laboratory and a similar construction loaded by traffic.

The RRL is planning to explore the possibilities of such a method of accelerated testing. An 80 kN capacity electro-hydraulic jack has been obtained, and will be mounted in a gantry spanning one of the pilot-scale laboratories at Crowthorne. This will be used to compare the stresses, strains and deformations induced by an impulsive jack load with similar quantities caused by a moving wheel in Road Machine No. 3.

## 5.8 Drainage

Two aspects of research on drainage are relevant to pavement design. The first is the control of the moisture content of the road structure itself, which may affect the choice of materials for the various layers of the structure. The second is the sub-surface drainage, which may affect the moisture content of the subgrade and hence its strength and stiffness.

Permeability measurements are being made of a range of roadmaking materials and soils in the laboratory, and a pilot-scale experiment is being constructed in the RRL grounds at Crowthorne to measure the effect of various treatments to the surface of the sub-base, and to check the in-situ permeability of certain basecourse and base materials. This permeability research should be completed in time to include the conclusions in the planned review.

A study has been made of the effect of deep drains on pavement strength and indicated that they may well be economic for silty-clay soils[35]. A pilot-scale experiment is planned to investigate the effects of deep drains on soil moisture and strength under a simple pavement[36], but this experiment may not be finished in time for the results to be included.

# 6. EXISTING PAVEMENTS

The whole of the preceding discussion has been aimed at improved methods for the design of new pavements, but much of it is also relevant to the problem of when and how to strengthen existing pavements. This problem is becoming more important as the number of heavy wheel-loads increases.

Studies with the manually-operated deflection beam over a period of years has led to deflection criteria for various constructions in sound condition and consequently to indications of impending failure. The acquisition of the vehicle-mounted Lacroix Deflectograph will allow greater lengths of road to be surveyed. Thus practical means are coming available whereby the strength of existing pavements may be measured in order to decide when they should be strengthened and by how much.

# 7. DISCUSSION AND CONCLUSIONS

The main lines of research on pavement design at the RRL have been described. They include continued study of the full-scale experimental pavements that form the basis of Road Note 29, together with more fundamental studies of structural theory, and of the behaviour of materials and pavements. The more fundamental work has already contributed greatly to the general understanding of pavement behaviour. It is being used to supplement the empirical data when improvements in pavement design are considered[37], and will be so used increasingly in the future.

The major value of the more fundamental research will however be the development of a method of pavement design based upon permissible stresses in the various layers which will limit the deformation or cracking to acceptable levels under given numbers of vehicles of various weights. A bonus would be the ability also to say when and by how much existing pavements should be strengthened to extend their service by a desired period.

The preparation of such a method means that several major lines of research have to be brought to an adequate stage at about the same time. The aim of the RRL programme is to reach in 4 to 5 years time at least an interim stage at which an assessment can be made of a method based on elastic theory and permissible stresses deduced from full-scale experiments and backed by a substantial volume of laboratory tests on materials. This would be a convenient period to consider a revision of Road Note 29 after the review due to take place in 1969. Such a revision could be made in a number of ways, the best of which does not have to be selected so far in advance The general form of Road Note 29 might be relatively unchanged, in that values for the thickness of the layers of various materials would be given for various soil conditions and traffic: the difference would be that the values would be chosen with the benefit of the theoretical framework and data on permissible stresses. On the other hand permissible stresses might be quoted for various materials, together with a method of calculation, so that the designer can incorporate his own cost data and optimise a pavement design for his given traffic and soil conditions. The decision on how to present an improved method will have to take into account developments in the specifications of materials and the possible use of 'performance tests'.

This stage should be a major advance but will not of course be final. The more critical results from the Alconbury and Wheatley By-passes will still be to come, the repeated loading programme on materials (particularly any new ones) will not be complete, and the full benefits of accelerated time testing of pavements on the pilot scale will not have been realised. Whether or not visco-elastic theory finds a place in practical design remains to be seen, but if it does it is unlikely to be in this time-scale.

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Printed at the Road Research Laboratory, Crowthorne, Berkshire, England

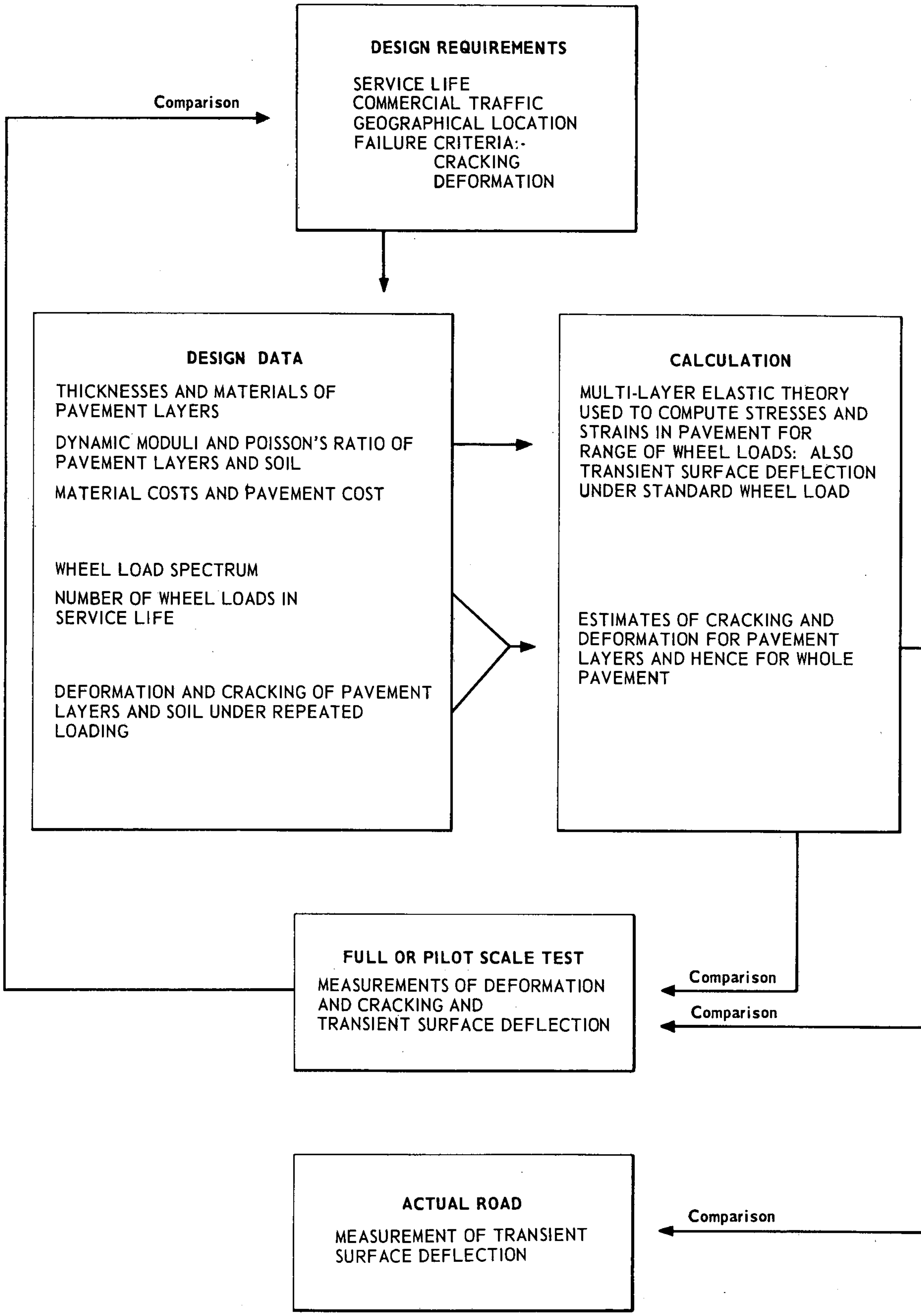


**Fig. 1 ANALYSIS OF GIVEN PAVEMENT DESIGN**

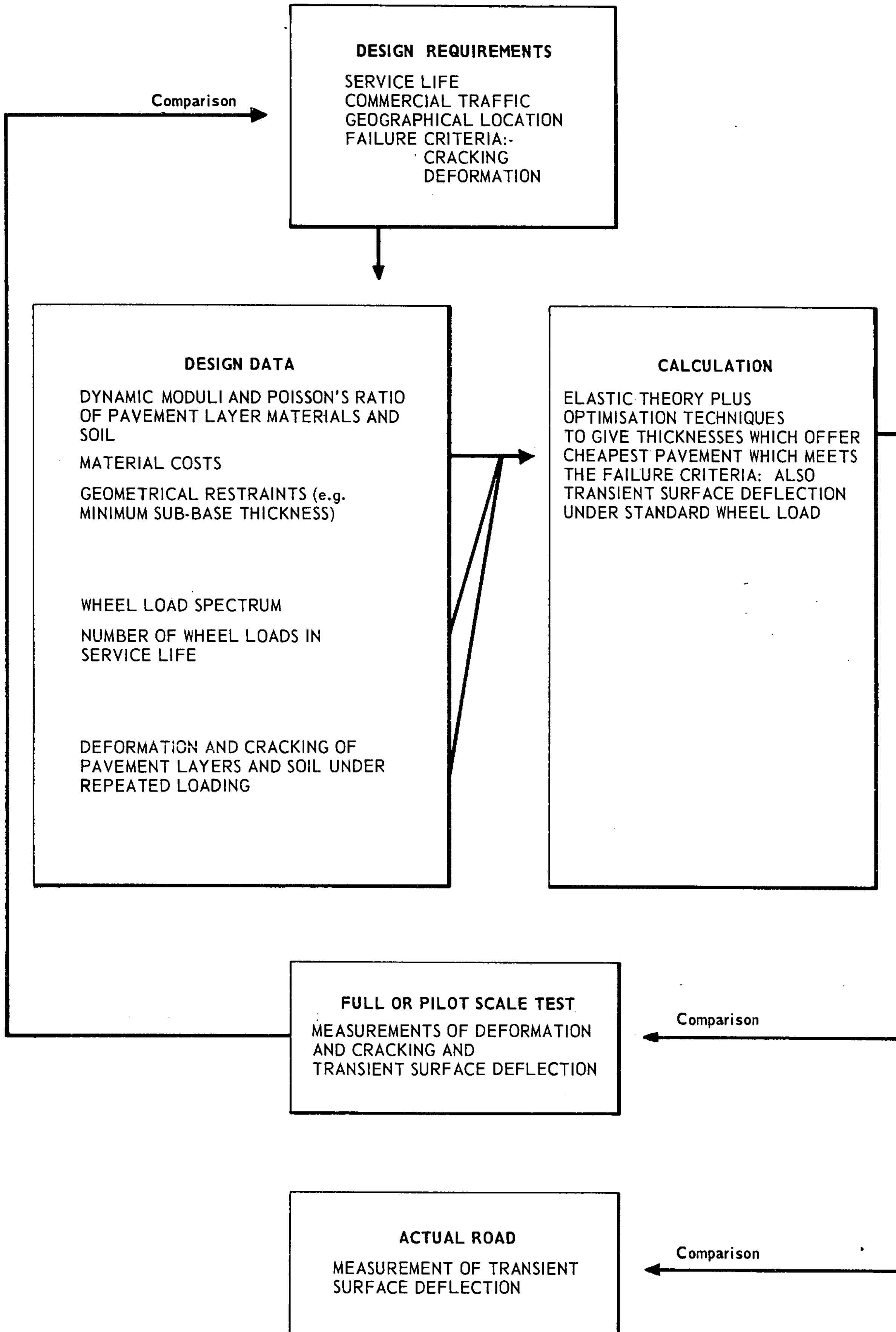


Fig. 2 OPTIMISATION OF PAVEMENT DESIGN

## ABSTRACT

**Research on pavement design:** M. E. Burt, BA Hons., C.Eng. F.R.Ae.S., Ministry of Transport, RRL Report LR 243: Crowthorne, 1969 (Road Research Laboratory). The basis of the structural design of road pavements in Britain is reviewed and compared with the design procedures used for other structures.

The need is stated for a method of pavement design based upon permissible stresses in the various layers which will limit the deformation or cracking to acceptable levels under given numbers of vehicles of various weights.

The preparation of such a method requires several major fields of research to be brought to an adequate stage at about the same time. The RRL research programme in these fields is outlined.