Three Full-scale Roads Experiments and their Implication in Relation to Pavement Design

Trois essais de routes en vraie grandeur et leur conséquence sur les projets de revêtements

by D. Croney, B.Sc.
and
G. F. Salt, B.Eng. A.M.I.C.E., Road Research Laboratory, Department of Scientific and Industrial Research, Harmondsworth, England

Summary

The paper describes three experiments on the design of flexible road pavements carried out in Great Britain on heavily trafficked roads since the last war. In each, sections of different thicknesses have been laid on subgrades of known properties. Studies have been made of the relative contributions of various base and surfacing materials to the performance of the pavement.

The results show that sections surfaced with hot rolled asphalt have performed better than similar sections surfaced with bitumen macadam. Where a hot rolled asphalt wearing course was used sections thinner than the CBR design thickness performed satisfactorily for periods up to 9 years (the duration of the observations). When bitumen macadam surfacings were used sections thicker than the CBR needed some maintenance of the surfacing to counteract the deformations that occured under traffic and restore a satisfactory riding surface.

Sections with a bound base (tar-coated stone) deformed less than similar sections using crushed stone and gravel bases.

Sommaire

Cet article décrit trois essais faits en Grande-Bretagne depuis la guerre, sur la constitution de revêtement souples pour les routes à grande circulation. Pour chacun de ces essais on a construit des revêtements de diverses épaisseurs sur des sols de fondation dont on connaissait les caractéristiques. On a étudié les contributions relatives de divers matériaux de base et de surface au comportement du revêtement.

Les résultats démontrent que les tronçons revêtus avec un béton bitumineux à chaud se sont comportés mieux que les tronçons semblables revêtus avec un macadam imprégné. Là où on a employé une couche de roulement en béton bitumineux à chaud, les tronçons d'une épaisseur moindre que celle indiquée par le CBR se sont bien comportés pendant une période de 9 ans (durée des observations). Là où on a employé une couche en macadam imprégné il a fallu réparer des tronçons d'une épaisseur plus grande que celle indiquée par le CBR pour corriger les déflexions qui ont eu lieu sous le trafic et pour rétablir une surface de roulement satisfaisante.

La déflexion des tronçons réalisés sur une couche de base en matière enrobée (pierre enrobée au goudron) était moins grande que celle des tronçons semblables construits sur une couche de base en pierre concassée ou gravier.

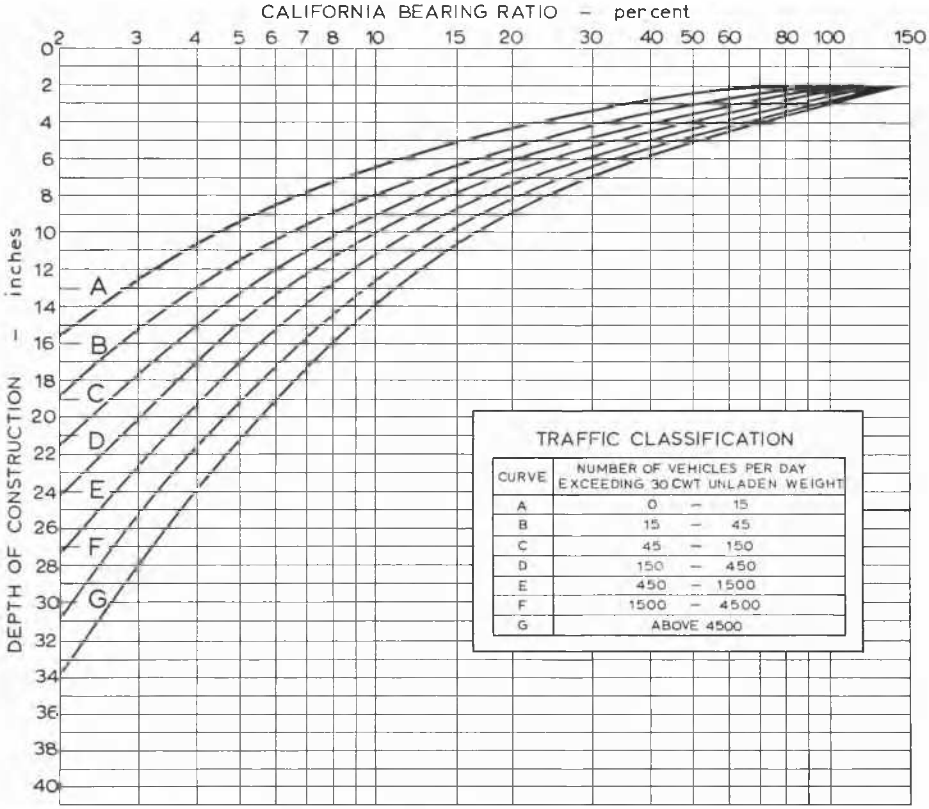
Introduction

Recent years have seen many changes in the types of materials being used for the bases, sub-bases and surfacings of flexible roads. Lean concrete, soil-cement, the dry and wet stone processes, and the use of dense bituminous and tar surfacings are all comaparatively new. Information is required on the thicknesses of these materials necessary in the road structure to give a pavement satisfactory for various traffic and soil conditions, and the relative abilities of the materials to perform their function. This is generally referred to as the problem of pavement design.

Since the original analysis of Burmister (1943) of the stresses and displacements in multi-layer pavements, progress has been made towards the development of a fundamental method of flexible-pavement design based on this approach (Fox, 1948 and Acum and Fox, 1951). The methods of design currently available, however, are largely empirical. In Great Britain, the California bearing ratio (CBR) test is widely used in conjunction with a family of design curves referring to different categories of commercial traffic (Fig. 1). This method is used at subgrade and sub-base level to determine the thickness requirements both for the pavement as a whole and for the base and surfacing, but it does not differentiate between the performance of different surfacing and base materials known to have widely differing load-spreading properties (Lee, 1956).

In the development and verification of methods of pavement design much can be done by observations on the behaviour of existing roads. Where, however, a direct comparison is required between the performance of a variety of forms of pavement structure, a specially designed full-scale experiment is essential to supplement preliminary laboratory research. In Britain experiments on existing highways are favoured in preference to test tracks employing artificial traffic, although use is being made of such tracks to examine the permanent deformation caused to pavements by repeated applications of different wheel-loads.

The principle followed in the full-scale road experiment is simple. Pavement structures of different thicknesses and employing different base and surfacing materials are laid side by side on a subgrade, the properties of which are known, and their performance is assessed at regular time intervals under traffic. The main criterion used to judge the performance of flexible pavements is the permanent deformation which takes place under the action of traffic. This is measured by observing periodically the levels of rows of studs located in the surface of the road and set at one foot intervals transversely across the carriageway. Three or more rows of studs are used in each section which would in general not be less than 60 ft. in length. In this way it is possible to determine the total deformation of the pavement and where, with respect to the



TRAFFIC CLASSIFICATION

CURVE	NUMBER OF VEHICLES PER DAY EXCEEDING 30 CWT UNLADEN WEIGHT
A	0 – 15
B	15 – 45
C	45 – 150
D	150 – 450
E	450 – 1500
F	1500 – 4500
G	ABOVE 4500

Fig. I CBR design curves for different classes of roads.
Graphiques CBR pour différentes catégories de routes.

width of the carriageway, the maximum deformation has occurred. In certain sections gauges may be installed to locate where within the pavement structure the deformation has occurred. Experience in Great Britain shows that highway authorities normally undertake repair work on their roads when the maximum permanent deformation of the pavement is of the order of 1 inch. This has therefore been adopted tentatively as one criterion of "failure". Thin sections may, however, deteriorate due to cracking arising from transient deflections under heavy wheel-loads. This results in surface deterioration and provides another criterion of "failure".

Description of the Experiments

The largest full-scale pavement design experiment at present in progress in Great Britain is located on one carriageway of a dual-carriageway section of trunk road A. 1 at Alconbury Hill, Huntingdonshire. Here the performance of 33 flexible sections and 37 concrete sections covering more than two miles of road is being observed. Since, however, the experiment was constructed as recently as the autumn of 1957 it is not proposed to discuss the results here. This paper is concerned with three earlier flexible-pavement experiments for which results are available covering periods up to nine years. A brief description of the sites and the scope of each experiment is given below.

Experiment 1 : on trunk road A. 1 north of Boroughbridge, Yorkshire—The experiment was constructed in 1949 on one 24-ft. carriageway of a dual-carriageway section, where the traffic (1958) is 2 700 vehicles per day (sum of vehicles in both directions exceeding 30 cwt unladen weight). The layout of the experimental sections is shown in Fig. 2. Three base materials were used (a) hand-pitched block stone (a traditional method then used in the area), (b) single-sized 2¼-inch crushed stone, blinded with dry fines and (c) tar-coated stone of nominal size 2¼ inches. Each of these materials was laid to the thickness shown in Fig. 2, under alternative surfacings consisting of 1½ inches of hot rolled asphalt wearing course on a 2½-inch tarmacadam basecourse and 1½-inches of bitumen macadam wearing course on the same thickness and type of basecourse. The experiment thus enabled the effect of changing the thickness of each base material under both types of surfacing to be studied, and in addition enabled a comparison of the relative performance of the three base materials to be made.

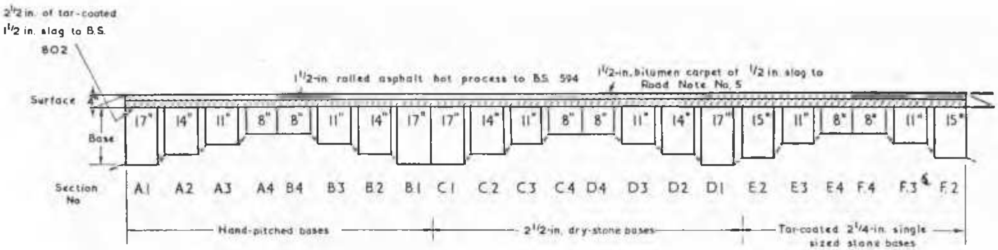


Fig. 2 Layout of the experimental sections for pavement design experiment trunk road A1.
Disposition des sections d'essai sur la route A1.

Experiment II : on trunk road A. 46 at Sapcote Junction, Leicestershire—The experiment was constructed in 1951 on a 32-36 ft. carriageway carrying vehicles in both directions, the traffic being 1850 commercial vehicles per day (1958). The layout is shown in Fig. 3. The subgrade was a medium clay of plasticity index in the range 14-25 per cent and average CBR value, determined on remoulded samples, of 4 per cent. Here two base materials, tar-coated limestone and dry crushed stone similar to that used at the first experiment, were laid to thicknesses of 8, 12 and 16 inches. A 3-inch tarmacadam basecourse was provided throughout the experiment, and a 1-inch hot rolled asphalt wearing course was added after the road had carried traffic for nearly two years. The experiment enabled the effect of changing the thickness of each base material to be studied, and gave a comparison of the relative performance of the two base materials. Information was also obtained on the effect that delaying the laying of the final wearing course had on the ultimate deformations of the sections. (This procedure of laying the wearing course after trafficking the basecourse is widely adopted in Great Britain).

Experiment III : on trunk road A. 38 *at Cambridge, Gloucestershire*—The experiment was constructed in 1954 on a 30-ft. carriageway carrying vehicles in both directions, the traffic being 2 400 commercial vehicles per day (1958). The layout is shown in Fig. 4. The northern end of the experiment was on a heavy clay soil of plasticity index 31 per cent and the southern end on a medium clay of plasticity index 22 per cent. The CBR values determined on remoulded samples varied between 4 and 6 per cent. Gravel and crushed limestone bases were used in thicknesses between 4 and 16 inches, and in some sections a sub-base of limestone quarry waste was used. The limestone bases were laid by the dry process(single-size material blinded with graded fines) and were similar to the crushed stone bases used in the two previous experiments. A 3-inch tarmacadam basecourse was laid at the time of construction and a 1½-inches wearing course of hot-rolled asphalt was added after the basecourse had been trafficked for various periods depending on the nature of the base. The objectives of this experiment were similar to those of Experiment II, except that the gravel base was used and the effect of a sub-base was investigated.

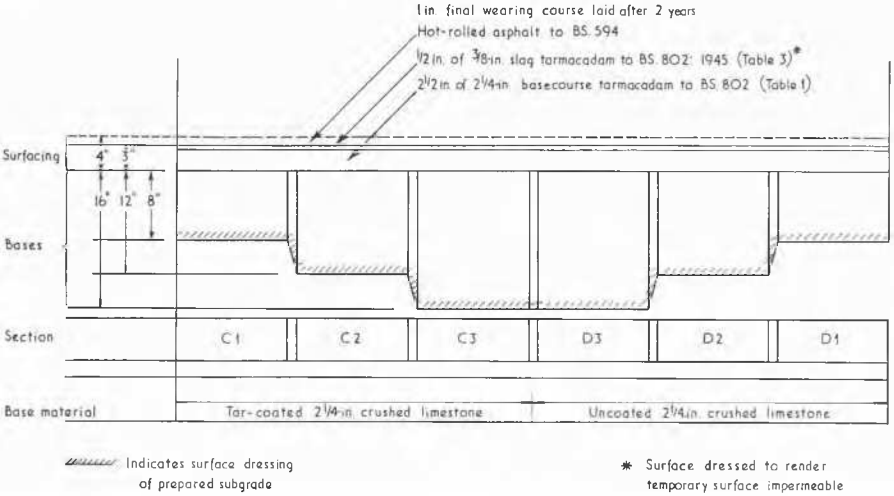


Fig. 3 Layout of the experimental sections. Trunkroad A 4b.
Disposition des sections d'essai sur la route A 4b.

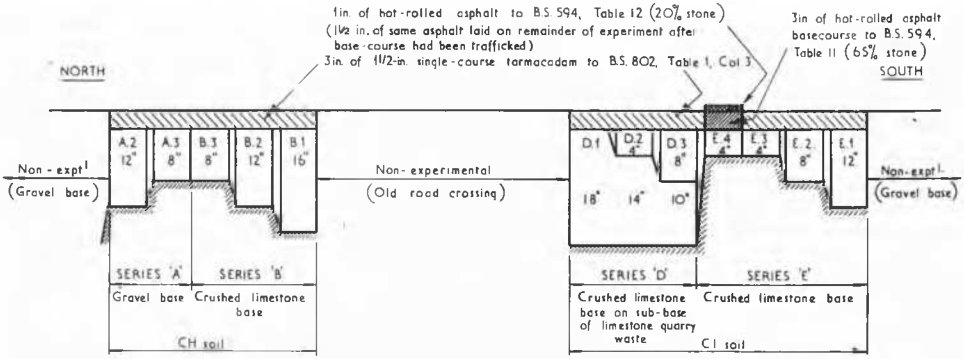
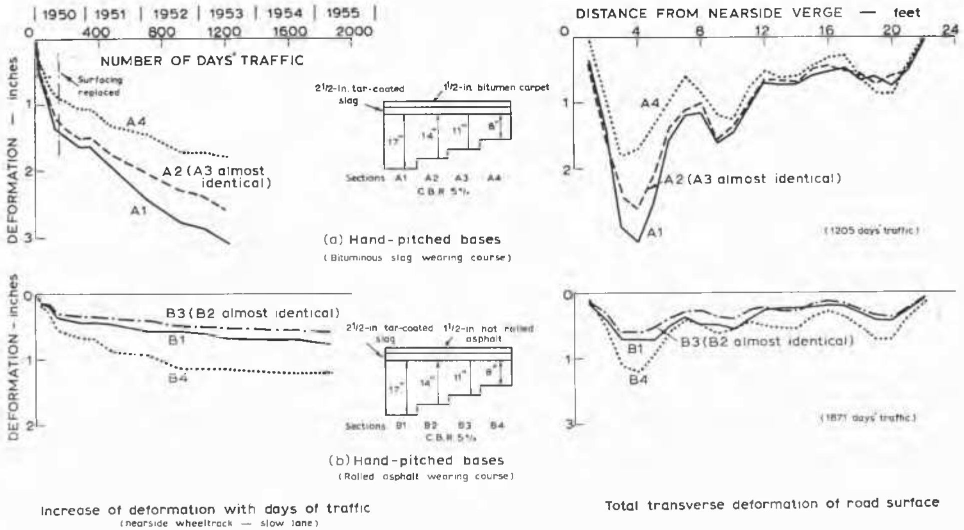


Fig. 4 Layout of the experimental sections. Trunk road A 38.
Disposition des sections d'essai sur la route A 38.

Summary of Results

Experiment I—The deformations measured in connection with the first experiment are shown in Figs. 5, 6 and 7, which refer to the hand-pitched, crushed stone and tar-coated stone bases respectively. In each of these figures the upper pair of diagrams refer to the sections surfaced with a wearing course of bitumen macadam and the lower pair to the similar sections surfaced with a wearing course of rolled asphalt. In each case the right-hand diagram gives for each section the transverse deformation of the road after the number of days traffic stated and the left-hand diagram shows the maximum deformation of the carriageway plotted against the number of days of traffic. The CBR values of the subgrade, determined on remoulded samples of the soil, are shown on each figure.

Referring to Fig. 5 (a) (hand-pitched bases with bitumen macadam wearing course), the deformation, as with all the other sections, was largely confined to the nearside traffic lane carrying more than 90 per cent of the heavy commercial vehicles. It was greatest for the thick bases and least for the thinnest base. This was because compaction of the base under traffic took place in addition to any shearing or compaction of the subgrade. (In 1950, the bitumen macadam wearing course was renewed and the original levels restored : the figures show the total downward movement of the road surface during the experiment and not the actual deformation after resurfacing, which can be obtained by subtracting the deformations that occurred before the resurfacing.) Under the rolled asphalt wearing course the deformations were much smaller; there was little significant difference between the performance of the three thickest sections, but there was evidence of soil compaction or shear beneath the thinnest section with the 8-inches base. No resurfacing of the asphalt was necessary during the experiment.



(a) Hand-pitched bases
(Bituminous slag wearing course)

(b) Hand-pitched bases
(Rolled asphalt wearing course)

Fig. 5 Comparison of deformation for identical sections surfaced with bituminous slag and rolled asphalt.
Comparison des déformations pour des sections identiques revêtues en laitier imprégné et d'enrobés à chaud. Couche de base en empierrement posé à la main.

The conclusions from these sections were that the traffic stresses transmitted to the base and subgrade through the bitumen macadam wearing course were sufficient to cause additional compaction of the base and shear of the subgrade. Under the rolled asphalt, which had a higher elastic modulus, the stresses in the base and subgrade were smaller and insufficient to cause significant additional compaction of the base, although there was an indication of some additional subgrade compaction or shear. The CBR design thickness for a pavement on a soil of CBR value 5 per cent would be 19 inches for the traffic carried by the road. Sections thicker than this figure required maintenance to preserve adequate riding qualities when surfaced with bitumen macadam but sections appreciably thinner performed satisfactorily for five years when surfaced with a hot-rolled asphalt wearing course. (After five years these sections were removed to enable another experiment to be carried out and further observations were not therefore possible).

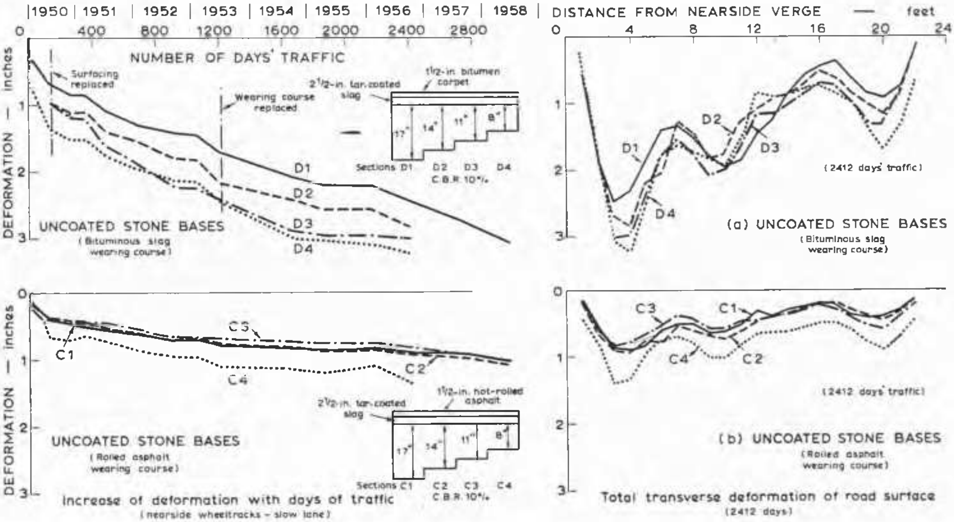


Fig. 6 Comparison of deformations for identical sections surfaced with bituminous slag and rolled asphalt wearing courses Uncoated stone bases.

Comparaison des déformations pour des sections identiques revêtues de laitier imprégné et d'enrobés à chaud. Couche de base en matériaux non revêtus.

With the bitumen macadam wearing course on the crushed dry stone bases, the deformations at first increased with decreasing thickness of pavement (Fig. 6 (a)). After some initial compaction of the base and soil under traffic the time/deformation curves were approximatel parallel suggesting that deformation of the subgrade was largely independent of the thickness of the base or compaction or shear in the surface of the base. On these sections, two replacements of the wearing course were necessary during the nine years covered by the observations, despite the fact that some of the sections were substantially thicker than the CBR requirement of 13 inches. There was no significant difference between the performance of the three thicker sections under the rolled asphalt wearing course (Fig. 6 (b)) but the stresses transmitted to the soil through the thinnest sections appear to have resulted in some additional compaction of the subgrade during the early life of the experiment. No maintenance of the asphalt wearing course was carried out.

The higher elastic modulus of the tar-coated stone bases (Fig. 7) resulted in a performance superior to that of the other two materials. Beneath the bitumen macadam wearing course the stresses transmitted to the base and the subgrade were sufficient to cause some progressive deformation but with the thicker bases this was less than with the other base materials. Under the rolled asphalt wearing course the deformations were very small and virtually independent of the base thickness. With the tar-coated base materials the effect of temperature on the elastic modulus of the pavement structure is particularly apparent from the increase in deformation occurring during the hot summers of 1953 and 1956. (A similar effect associated with the surfacing materials is also noticeable in the sections employing the other base materials). Again, sections thicker than the CBR requirement of 11 inches, required maintenance to give a satisfactory pavement with a bitumen macadam surfacing but no maintenance was required in nine years for the sections with the rolled asphalt wearing course.

Experiment II—The deformations measured in this experiment are shown in Fig. 8 using the same method of presentation as for Experiment I. The transverse deformation curves are different in form from those in Experiment I because the road carried traffic in both directions. Fig. 8 (a), refers to the tar-coated bases and Fig. 8 (b) to the uncoated crushed-stone bases. Allowing for the lighter traffic (only two-thirds the volume at Experiment I) the deformations for the sections with tar-coated bases at the time when the asphalt wearing course was laid were virtually the same as those measured for the tar-coated stone sections under the bitumen macadam wearing course at Experiment I. This was the case despite the thinner surfacing and the lower CBR value of the subgrade at Experiment II. The rate at which deformation continued

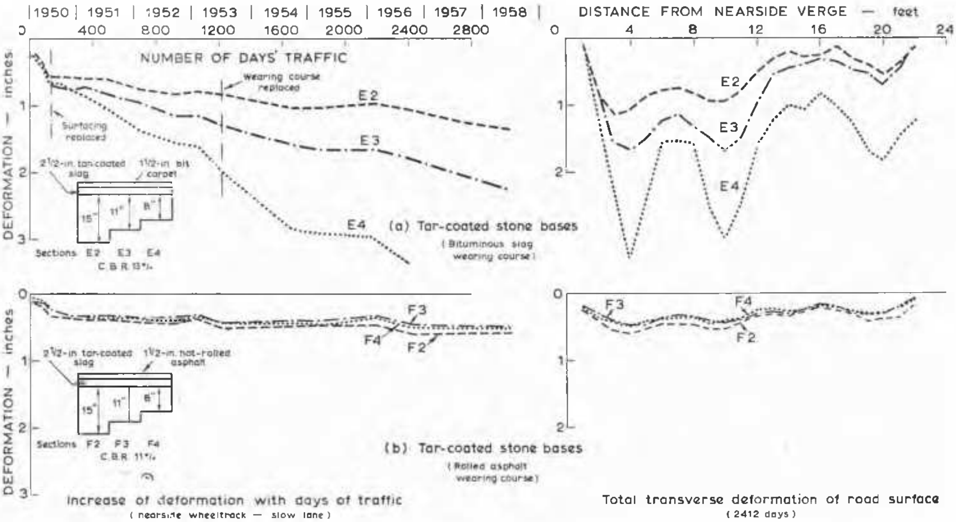


Fig. 7 As Fig. 6. Tar. coated stone bases.
Comme Fig. 6. Couche de base en matériaux revêtus de goudron.

after the laying of the asphalt wearing course was also very similar to the rate of deformation measured for the tar-coated bases under the rolled asphalt wearing course at Experiment I. The thickness of the base had no significant influence on the deformation after the asphalt was laid.

The uncoated-stone bases on Experiment II deformed less than those of comparable thickness under the bitumen wearing course on Experiment I, even after allowance was made for the different traffic intensities. This was probably due to a rather superior grading of the material, which enabled better compaction to be achieved, so reducing subsequent traffic compaction. The rate of deformation of these sections after the laying of the asphalt wearing course was similar to that of the comparable bases in Experiment I under the rolled

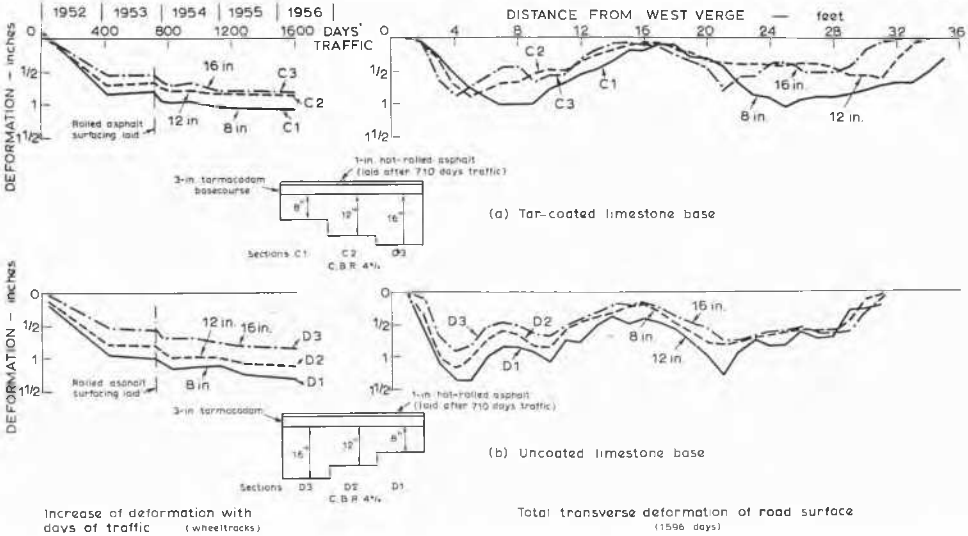


Fig. 8 Comparison of deformations of sections of the same thickness with tar-coated and uncoated limestone bases.
Comparaison des déformations de sections de même épaisseur avec des couches de base en matériaux calcaires revêtus de goudron et non revêtus.

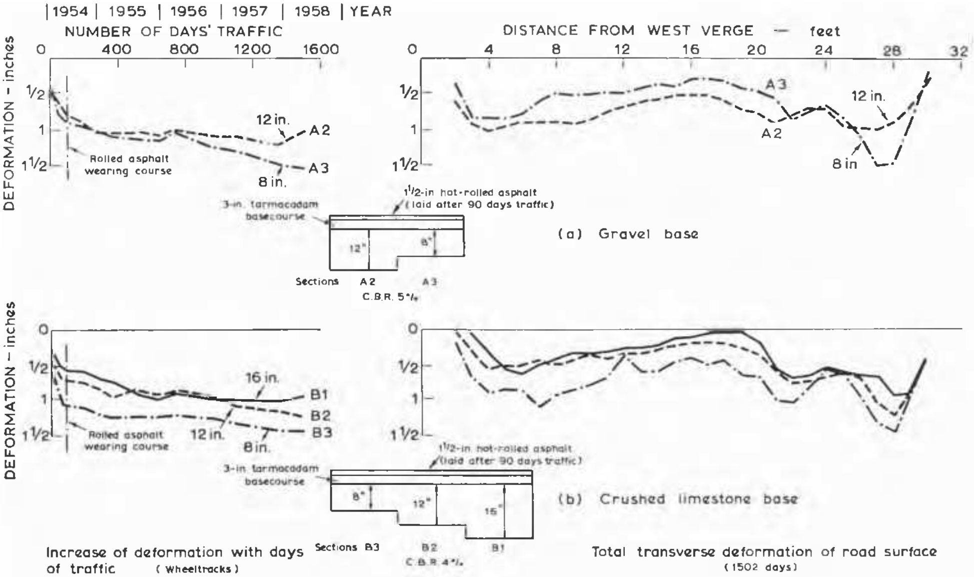


Fig. 9 Comparison of deformations of sections with gravel and crushed limestone bases (TR A 38).
Comparaison des déformations de sections comportant des couches de base en calcaire concassé et en grave.

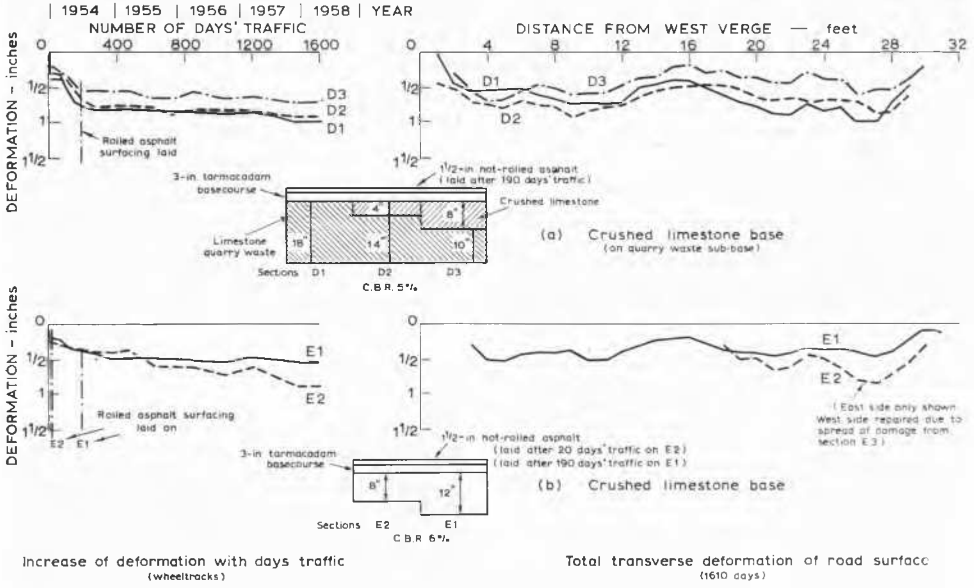


Fig. 10 Comparison of deformations of sections with crushed limestone bases (TRA 38).
Comparaison des déformations de diverses sections à couche de base en calcaire concassé.

asphalt wearing course and was greater than that for the sections with tar-coated bases. There was little difference, however, between the performance of the three thicknesses of base after the asphalt was laid.

The experiment showed that the ultimate deformations of the pavement were reduced when the laying of the asphalt wearing course was delayed until the road structure had carried traffic.

Experiment III—The results are presented (Figs. 9 and 10) in the same form as previously adopted. The deformation of the sections with dry crushed stone bases at the northern end of the site (Fig. 9 (b)) were, before laying the asphalt wearing course, slightly smaller than those measured on the comparable sections under the bitumen macadam wearing course at Experiment I. This was despite the thinner surfacing and the lower strength of the subgrade at the later experiment. The rate at which deformation continued after the laying of the asphalt was very similar to that of the comparable sections under asphalt at Experiment I. At the southern end of the experiment, where the crushed-stone bases were repeated, the asphalt wearing course on the section with an 8-inch base was laid very shortly after the road was opened to traffic. This reduced the initial deformation but did not affect the rate of deformation after the wearing course was laid. The initial deformation of the 12-inch base was rather less than at the northern end of the experiment. The well-graded gravel bases (Fig. 9 (a)) did not perform very differently from the crushed stone bases, but there was rather more evidence of subgrade shear under the 8-inch gravel base.

The use of the quarry sub-base material (Fig. 10(a)) reduced slightly the initial deformation of the sections and also the rate of deformation after the provision of the asphalt wearing course. It was clear that the performance of the quarry-waste material was only marginally inferior to that of the crushed stone used in the bases.

At this site the sections E. 3 and E. 4 with 4-inch crushed-stone bases failed very rapidly due to cracking resulting from transient deflections under the heavier wheel-loads. Permanent deformations were small when the surfacing began to break up. These sections were replaced by similar sections with 6-inch bases. These were reconstructed after $2\frac{1}{2}$ years, again due to cracking and pot-holing of the surface, when the average permanent deformation was of the order of $\frac{3}{4}$ inch.

Conclusions from the Experiments

(1) The principal conclusion relates to the effect of the surfacing on the performance of the sections. The use of the hot rolled asphalt surfacings resulted in much less deformation under traffic irrespective of the type of base material. (This has also been confirmed from the later experiment at Alconbury Hill where the relative performance of 4-inch rolled asphalt and bitumen macadam surfacings has been investigated.) There was evidence that with the base materials used, delaying the laying of the wearing course of asphalt until the basecourse had been trafficked resulted in smaller ultimate deformations. (This might not apply if the basecourse was insufficiently strong to prevent overstressing of the base before the wearing course was laid.)

(2) The tar-coated base material gave structures less liable to deformation that the hand-pitched, crushed-stone and gravel base materials used.

(3) The crushed-stone, limestone quarry waste and gravel base materials used in the experiments performed in a similar manner (The gradings of the materials did not cover a wide range and further experiments are being carried out to investigate the importance of grading in both bound and unbound base materials.)

(4) Even in the absence of a sub-base, increasing the thickness of base to more than 11 inches led to no significant improvement in the performance of the sections under rolled-asphalt wearing courses.

(5) Sections surfaced with bitumen macadam wearing courses deformed sufficiently to necessitate periodic maintenance even when the overall thickness exceeded that required by the California bearing ratio method of design. Such sections could however, be maintained by attention to the surfacing alone. Sections surfaced with rolled asphalt wearing courses performed satisfactorily (for the periods investigated) even when the total thickness of construction was substantially less than the CBR design thickness.

Acknowledgments

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