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16. ABSTRACT

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For a number of years, all concrete pavements constructed by the California Division of Highways have been placed on specially treated or hardened subgrades. The first project was constructed in 1946 on the coastal highway between San Diego and Los Angeles. This was followed by other projects and for the past ten years no concrete pavements have been placed on untreated subgrades. In the majority of cases, portland cement was used although in certain instances sandy subgrades were treated with asphalt.

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Historical

By 1944, the Division of Highways was becoming increasingly concerned over the widespread evidence of troubles at the joints in concrete pavements. California had followed the general trend of national practice in the design and construction of concrete pavements. Prior to 1922, pavements 4-in. in thickness were constructed without expansion or contraction joints. Later, when the standard thickness was increased to 5 in., a 2-in. expansion space was left at the end of the pour at noon or at night. These spaces were later filled with mixtures of asphalt and sawdust to form an expansion joint.

Buckles or "blow-ups" were fairly common in the older thin pavements without joints, and after expansion joints were constructed at intervals of several hundred feet, intermediate cracks continued to develop, often accompanied by some small spalling or chipping at the edges. These cracks were unsightly upon close inspection, and as cracks in buildings or other concrete structures are usually regarded with concern and considered to be evidence of failure, similarly, it became rather common practice for engineers to class cracks in pavements as evidence of "failure".

In order to counter this natural tendency of concrete pavements to develop transverse cracks through shrinkage, steps were taken to anticipate the cracking and improve the appearance by placing weakened planes at closely spaced intervals. The question of what spacing is appropriate is still debatable and practices vary throughout the United States.

Some 30 years ago, we required expansion joints every 60-ft. with contraction joints at 20-ft. intervals. Following national practice dowels were placed across the joints, first at 28-in. centers and later at 15-in. spacing. Nevertheless, with all these precautions and features of "modern design" concrete pavements were giving trouble at the joints which became so serious that by 1944 some engineers began to question whether the use of concrete pavements should be continued and at the very least there was a pressing need to find means for preventing troubles that develop at the constructed joints.

An extensive investigation was launched in 1944 for the purpose of determining the causes of troubles at the joints in concrete pavements and, if possible, to recommend a solution or corrective means. A report of a similar investigation conducted by the Portland Cement Association came to hand about this time. This report placed emphasis on the nature of the soils which were found to pump through the joints in concrete pavements. It led to the belief among certain engineers, at least in this State, that all that would be necessary to avoid trouble was to eliminate certain types of silty soil from the subgrades. However, the investigation of California pavements conducted during the years 1944 to 1946 indicated quite clearly that there was no type of untreated soil, even including sand and gravel subgrades, that consistently prevented the development of trouble at the pavement joints. It was also obvious that a certain amount or weight of traffic was necessary to produce pumping and faulting but this level was rapidly being approached or exceeded on the majority of concrete pavements in California even 15 to 20 years ago.

It has been common knowledge for many years that portland cement concrete is subject to volume change due to variations in temperature and variations in moisture content, and the fact that both portland cement and mineral aggregates individually exhibit such characteristics suggests that it would be very difficult, if not impossible, to prevent mixtures of these materials from also expanding or contracting. However, our study of pavements brought forth evidence that there is a considerable variation in the volume change properties of different concretes. The data indicated that the coefficient of expansion due to temperature was fairly uniform; therefore the greatest variation was in response to moisture.

Engineers have long assumed that deflections at the end of individual slabs were due to depression of the subgrade because of load transmitted by the unsupported slab ends. Our study brought no evidence of increased density of silty or clay soils under the ends of the slab but indicated rather that the primary cause of troubles originated with the warping and curling of the slabs providing space for the accumulation of water between the slab and the subgrade. Simple calculations indicate that even with a small monolithic slab similar to the portion often broken from the longer slabs, pressures on the subgrade under the tandem axles carrying a 32,000-lb load would not exceed 7 psi if distribution is assumed to be uniform. Reports of actual tests have never disclosed more than 6 psi. Hence, unit load on a subgrade under an 8-in. concrete slab cannot be of much consequence.

During the period 1925 to 1930, there were a number of resurfacing projects where old concrete pavements had been resurfaced with concrete and it was noticeable that there were no joint problems, almost complete absence of faulting at the joints or cracks, and all in all these pavements had given an excellent performance even where the original pavement was over some very poor silt and clay soils. Reports from other states gave accounts of excellent performance of concrete pavements over old macadam surfaces. Also, the evidence produced in California and elsewhere was quite consistent in indicating that the pumping action of slabs under heavy traffic tended to churn up the subgrade soil whenever enough water accumulated beneath the pavement and as a result the supporting soil was pumped out whenever there was enough water present.

Reasoning from these observations, it was concluded that if the subgrade could be treated or modified by some means so that it would resist erosion, then the concrete pavements should give long, fairly trouble free service. In other words, even though the slabs curl and warp and movement of the slab ends continues, the effects are not too serious provided the subgrade remains in place and maintains its original plane as constructed -- conforming to the underside of the slab.

Seeking means for establishing this condition, the use of portland cement appeared to be most logical. The first trial was made in 1946 on a section of mainline highway between San Diego and Los Angeles. Here, the subgrade material was scarified after the side forms were in place and treated with about five percent of cement, using road-mixing equipment. Virtually all of the treated subgrades beneath concrete pavements in California have been constructed by the road-mix method whether cement or asphalt was used, although there have been one or two cases where the contractor elected to mix the material in a central plant. A depth of 4-in. was adopted at that time and has become the standard thickness for cement treated subgrades. After this cement treated material has been thoroughly mixed, it is compacted by rolling and then trimmed with a subgrade machine in the normal manner. After being trimmed and given a final rolling, the surface is covered with a heavy application of cutback asphalt ranging from .20 to .25 gals. per square yard. It must be emphasized at this point that this application of asphalt has two purposes; first, of course, to provide a curing seal to prevent the loss of moisture and develop the benefits of the cement treatment, but more important, it is intended to provide a surface that will resist erosion. Ordinary soil-gravel mixtures treated with four per cent or five per cent of cement will not resist abrasion under traffic. Cutback asphalt is not necessarily the ideal material but it is considered essential that this asphalt seal be retained by the cement treated subgrade so far as possible. Emulsified asphalts are often more convenient to use and form a very effective curing seal. Emulsified asphalt has been used very extensively for cement treated bases which are covered with an asphalt concrete pavement. However, any layer of asphalt placed on a subgrade and then covered with a concrete pavement has a strong tendency to adhere tenaciously to the underside of the superimposed concrete slabs and when this happens the asphalt film will be pulled upward and leave the cement treated subgrade without protection when the concrete slabs curl upward at the ends as invariably occurs at some season of the year or at some time of the day.

Laboratory trials indicated that cutbacks would penetrate the average cement treated subgrade layer to depths ranging from 1/4-in. to 1/2-in., and, therefore, even though a superficial layer of asphalt adheres to the concrete, it is expected that there will be a sufficient amount of impregnation in the cement treated subgrade to resist erosion when water is churned back and forth by the pumping action of the slab ends.

It may be noted that two different terms are used and we have drawn a distinction between cement treated subgrades and cement treated bases. Asphaltic pavements require a base. In the past cement treated bases in California have usually been constructed 8-in. in depth and sometimes more. Concrete pavements, on the other hand, were considered to have adequate structural strength if uniformly supported. Therefore, where concrete pavements have been involved, a cement and/or asphalt treatment has been used only to produce an erosion resistant subgrade. For this purpose, strength and thickness of layer have not been primary considerations. This distinction in terminology has at times created some confusion and future specifications will probably refer to all such treatments as cement treated base or CTB regardless of whether the superimposed pavement will be portland cement or an asphaltic type. Also, with the increased volume of traffic, consideration is being given to heavier structural sections and it is quite probable that the cement treatment under concrete pavement will be increased to 6-in. or more with the intention of affording additional support, especially under the outer traffic lane which must sustain the bulk of the heavy vehicles.

One recognized inadequacy with the present methods of construction when the cement treated subgrade is mixed and compacted after the side forms are in place is the fact that this hardened and treated layer does not extend beyond the width of the concrete slab. It is generally agreed that it would be better design if the cement treated subgrade were wider than the pavement. Evidence from both the WASHO and AASHO test roads indicates that in general pavements are more vulnerable along the outer wheel track than along the inner wheel track. Therefore, extending the hardened subgrade should give greater protection and would also serve as a support for the adjoining border treatment. Thus far it has appeared to be impractical to place the cement treated subgrade to a true grade without using side forms and it has been considered to be too difficult to place side forms on top of a cement hardened subgrade. The problem of placing a wider base may, however, be readily solved with the advent of the slip form paver. It seems inevitable that slip form pavers will, sooner or later, supplant the present methods of placing concrete pavement. If the pavement is placed with a slip form paver there will be no problem in placing the cement treated subgrade first and to any width and length desired. The ultimate success of slip form pavers will, of course, depend upon the ability to produce pavements having acceptable riding qualities. It now seems probable that this problem can be solved. However, if the pavements are to be smooth on the surface it is probable that we will have to accept some variation in thickness of the slab.

Results

The first project using a cement treated subgrade has been under traffic for 13 years and is still in excellent condition. Taking the entire experience where we now have 900 miles of this type of construction, we have, for all practical purposes, eliminated the problems of pumping joints. While curling and warping of the slabs have not been eliminated, the adverse developments are so far relatively minor. It cannot be claimed that the cement treated subgrade is a 100 per cent answer to the problems arising from joints in concrete pavements, and it is evident that some of the sections are less effective than others for unknown reasons. There are a few jobs where faulting has developed up to 1/8-in. and while thus far none of these can be regarded as serious, nevertheless, they furnish evidence that further improvement is possible.

For a few years following construction, there were some doubts as to the suitability of the asphalt treated subgrades where cohesionless sand was road-mixed with RC cutback for a depth of 3-in. However, a recent survey of all sections over asphalt treated subgrades indicates that they average up equally well and in some cases better than the cement treated subgrades. This may be partly due to the fact that asphalt treatment has been used only where clean sands or gravels were in place and have not been applied to soils containing high percentages of clay as has often been the case with cement. Therefore, it can be concluded that with proper selection of materials either cement or asphalt can be used to form a suitable subgrade which will stay in place and withstand the vertical movement and pumping action of the pavement slab ends. It should be further emphasized that the only steel used in California concrete pavements are the tie bars across the longitudinal center joint. Neither dowels nor reinforcing steel are used as standard practice.

It may be of interest to many to note that ejection of material along the edges of the slabs is virtually unknown in California pavements. This phenomena is often referred to as "blowing" in eastern states but has never been observed on any concrete pavements over cement treated or asphalt treated subgrade in California.

Figures 1 to 15 illustrate the typical steps and equipment used in constructing a cement treated subgrade according to California practice.

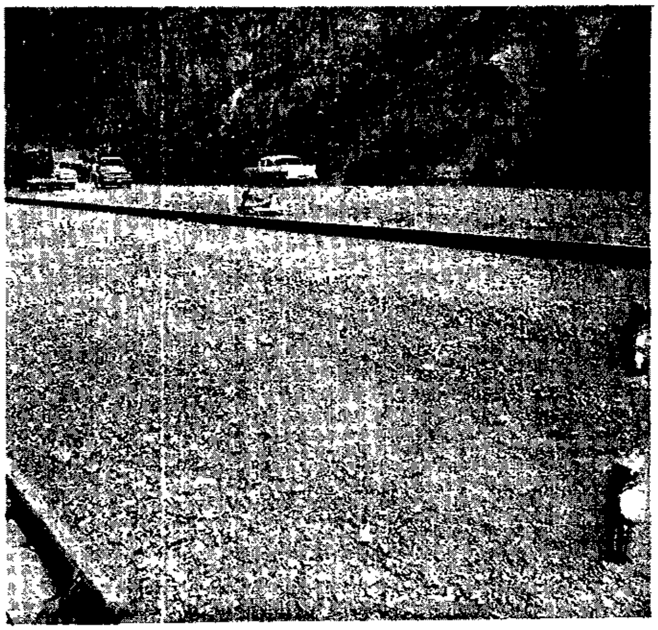

Fig. 1

Subgrade material and side forms in place before beginning subgrade operations.

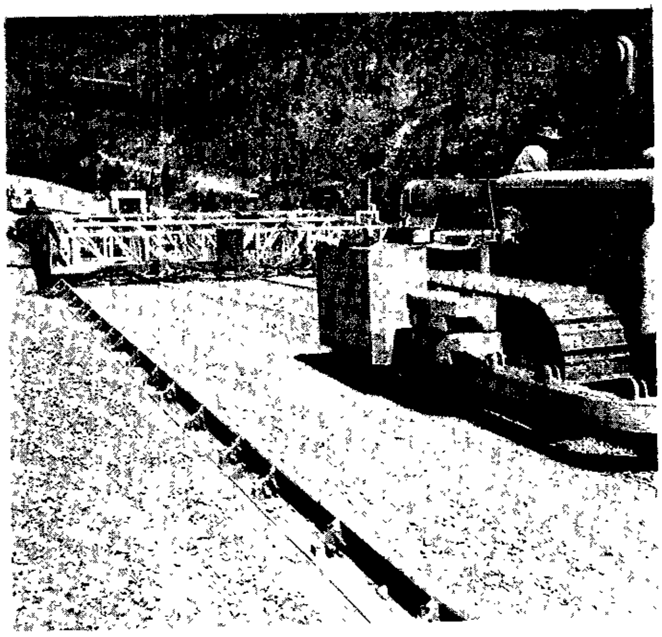

Fig. 2

Subgrader (Scarifier and Windrower) in operation on subgrade material.

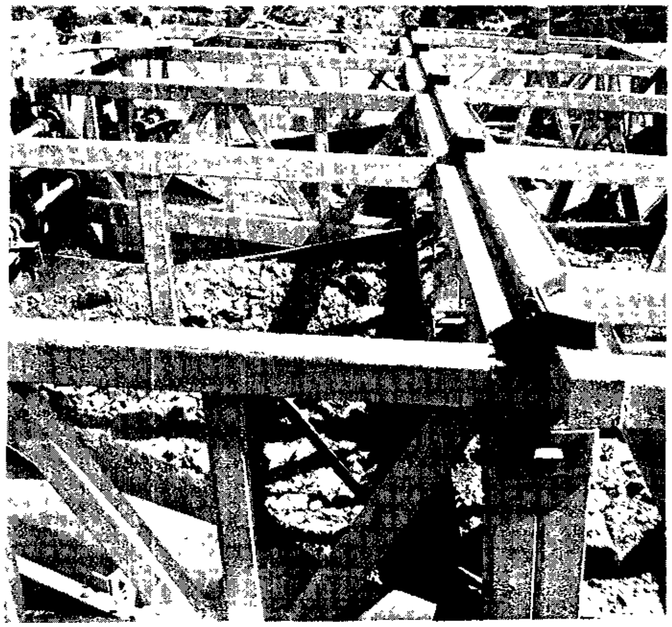

Fig. 3
Windrower section of 'subgrader'
in operation.

Fig. 4
Dual windrows shaped by 'subgrader'.

Fig. 5
Cement treated subgrade - Windrow machine.

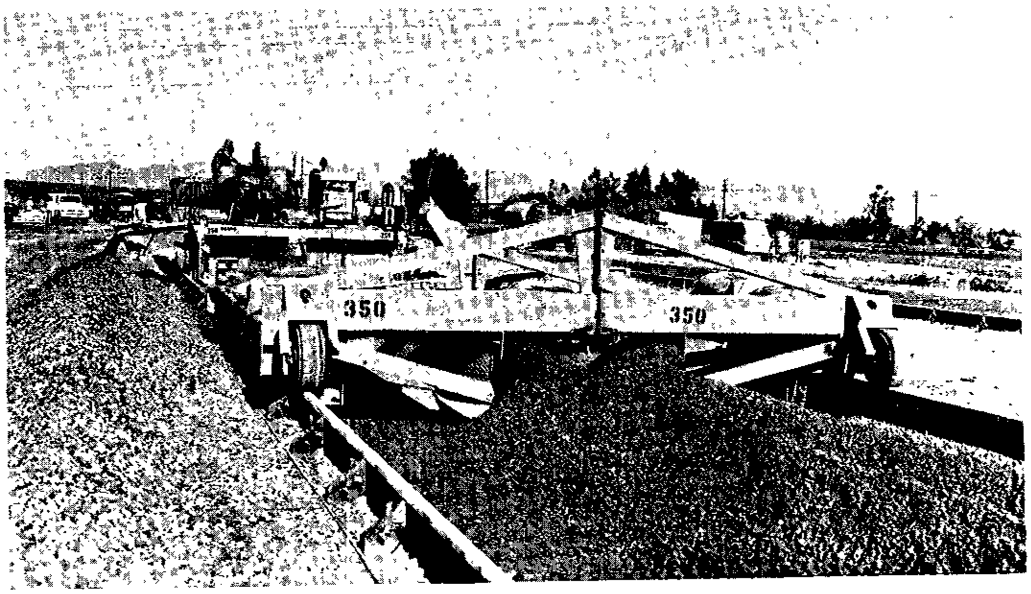

Fig. 6
Cement treated subgrade. Another type of Windrow machine.

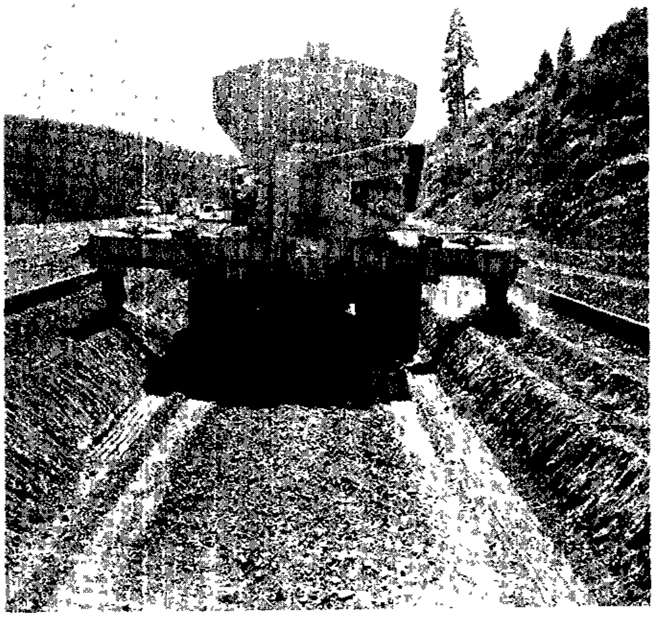

Fig. 7

Distributor truck depositing cement in 'V' notch of each windrow.

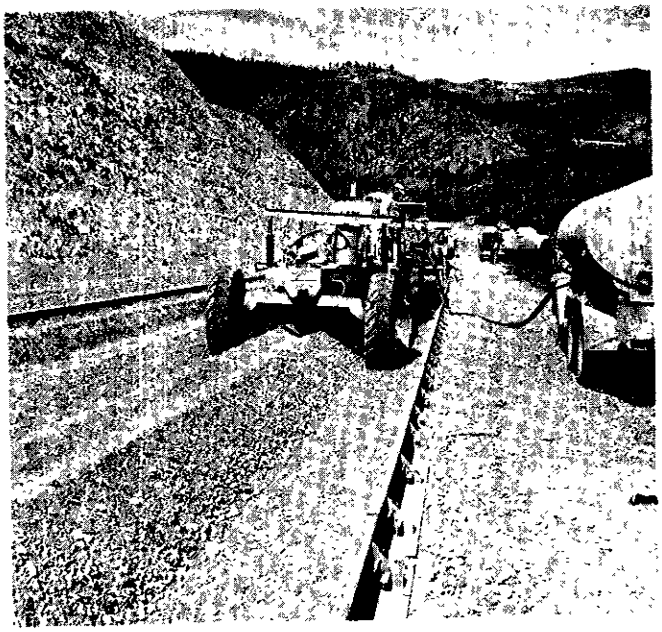

Fig. 8

Traveling road mixer in operation on inner windrow.

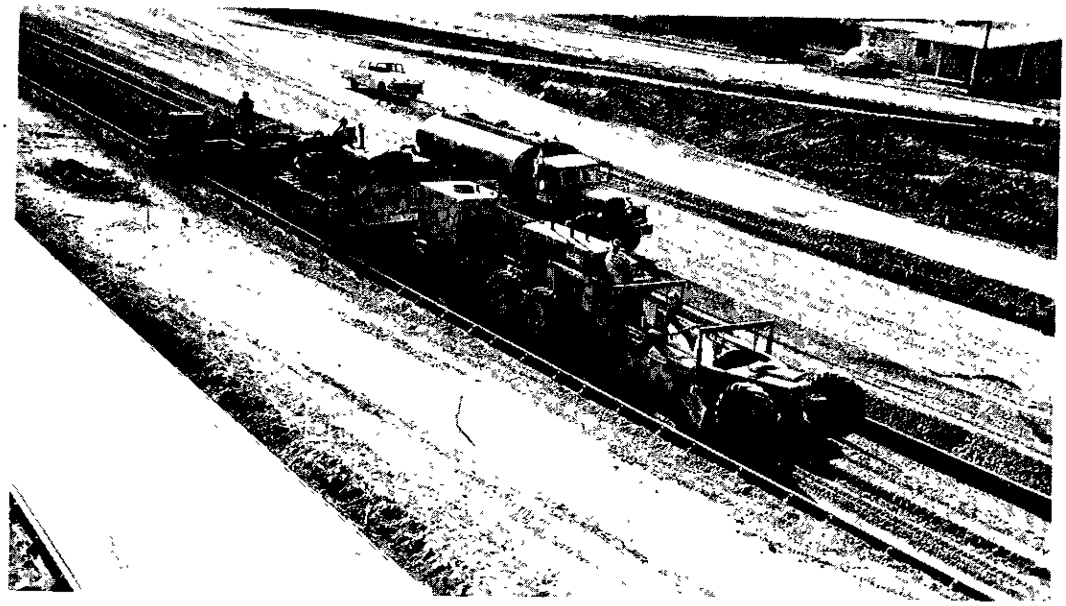

Fig. 9

Cement treated subgrade - Mixing

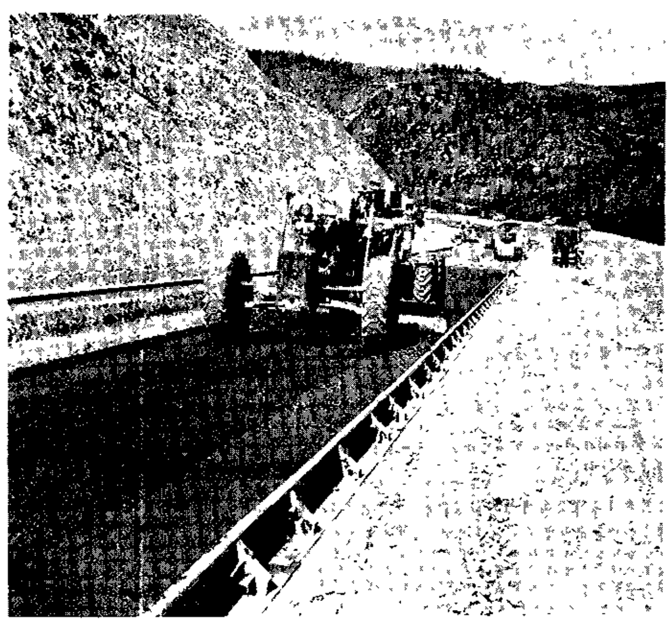

Fig. 10

Grader starting to complete spreading of mixed subgrade material.

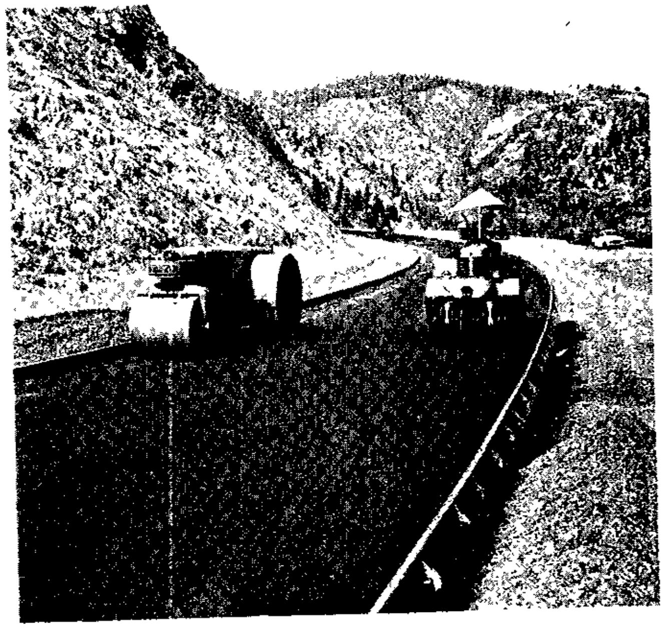

Fig. 11

Steel tired and pneumatic rollers. Note fog spray application by pneumatic roller.

Fig. 12

Pneumatic tired roller on C.T.S. Note fog moisture application.

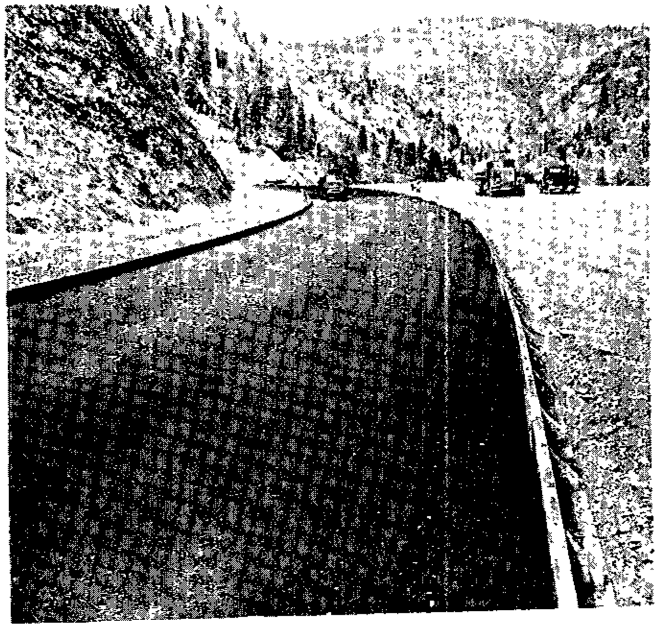

Fig. 13

Subgrade in place - ready for curing seal.

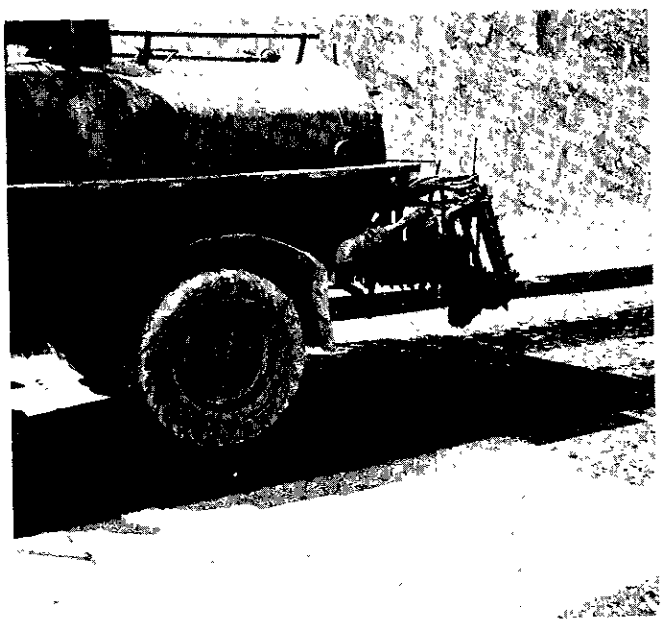

Fig. 14

Curing seal 'boot truck'.

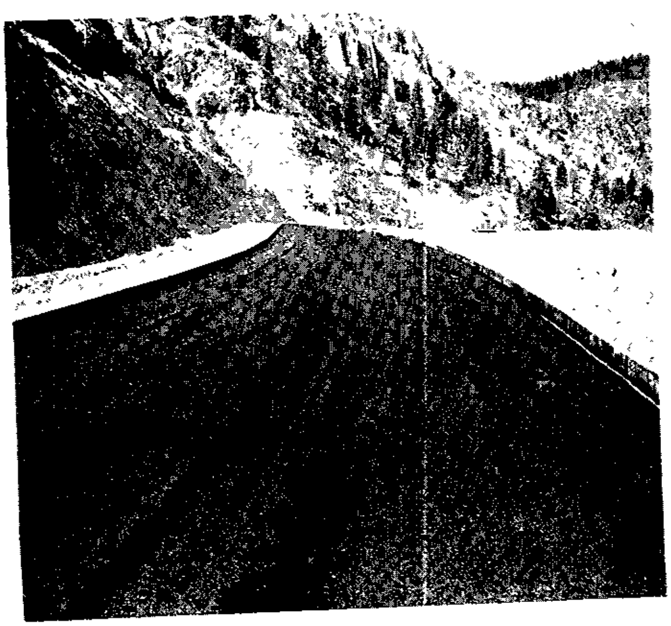

Fig. 15

Cement treated subgrade after application of curing seal.