Performance of Concrete Pavements as Related to Subbase Construction Methods

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Field studies of the performance of concrete pavements built on subbases of various designs and materials show that the method of subbase construction is an important factor. Uniformity of gradation was found to be the one subbase quality having the most influence on pavement performance. Subbase materials having a small maximum size were found generally to perform better than coarser materials because segregation is less likely to occur during placement.

Information was obtained during the construction of 28 projects in many parts of the country representing typical subbase construction methods. The effects on subbase density and gradation of various construction operations are discussed. These include methods of subgrade compaction, subbase mixing, placement and compaction, and fine-grading.

Heavy construction traffic on the completed subbase nullifies the efforts expended to obtain uniformity and results in substandard pavement performance.

● SINCE 1952, the Portland Cement Association has been engaged in an extensive study of subbases for concrete pavements. This study has been carried on in cooperation with the state highway departments of New York, Missouri, Indiana, Michigan and North Carolina. The purpose is to study the relative performance of pavements built on subbases of various designs and thicknesses and representing a variety of materials, in order to establish minimum subbase requirements for a wide range of traffic, soils and climatic conditions.

During the course of these studies it became increasingly apparent that the practices employed in subbase construction have an important influence on pavement performance. One of the main reasons for using subbases is to prevent pumping. Therefore, a careful investigation was made wherever joint pumping was observed on pavements built on subbase. In each case the cause of the pumping was traced to one or more improper construction practices. In some cases gravel had come from a pocket of inferior material in the pit or had become mixed with an excessive amount of overburden material. In others a leveling course of fine-grained soil had been placed on top of the subbase, or the subgrade soil had been mixed into the subbase by construction traffic during wet weather. In one case, for example, the subbase had been exposed to heavy truck traffic throughout an entire winter and at times trucks had become mired down so badly that they had to be towed across the project. By the time of paving, the subbase was badly contaminated and since it was not replaced, pumping developed. The appearance and gradations of the materials under the pave-

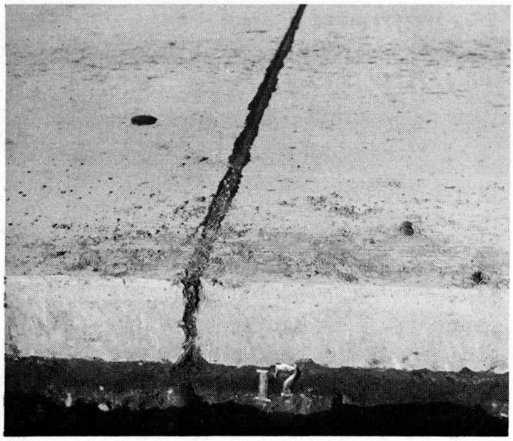

Figure 1.

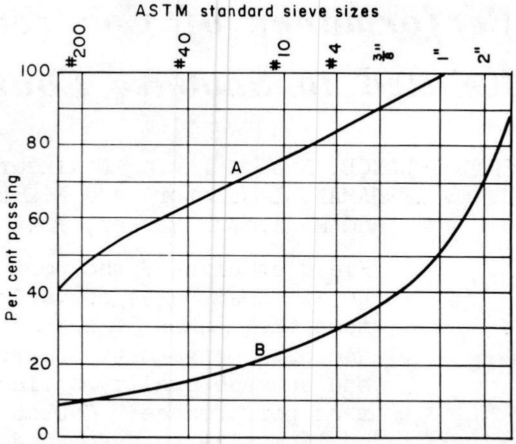

Figure 2.

ment on this project are shown in Figures 1 and 2. Curve "A" shows the gradation of material directly beneath the pavement. This layer varied in depth from 2 to 4 in. Curve "B" shows the gradation of the subbase layer buried below 2 to 4 in. of soil susceptible to pumping.

Another purpose of subbases is to control frost action. In some cases when the subbase was placed in such a manner that it became badly segregated, differential heave has occurred within the granular layer itself. Areas which are deficient in fines act as reservoirs for the collection of water, which can lead to the formation of ice lenses in adjacent areas which have excessive amounts of fine material. When the pavement and subbase are frozen solidly together, the differential heave can cause cracking in the pavement and an uneven surface.

In many cases variable performance occurs within individual projects. On many of these projects the type of soil, sources of materials, and traffic are the same from one end of the project to the other, and the pavement and subbase design and climatic conditions are uniform throughout. On one 10-year old project, for example, there are some sections in excel-

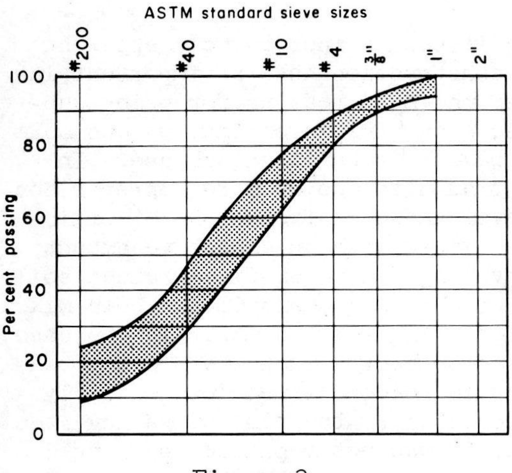

Figure 3.

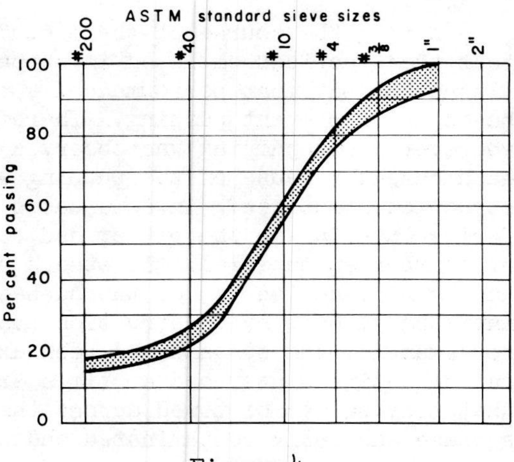

Figure 4.

lent condition, while others have not performed as well as expected. Two sections of this project were selected for detailed subbase sampling, one representing the good performance and one representing the poor performance. In each section six samples of subbase material were removed from under the heavily traveled lane of pavement at 10-ft intervals. Samples from the section with poor performance have wide variations in gradation as shown by the band in Figure 3. The gradation of the sample at one location may be along the top of the band while that of a sample from only 10 ft away may be near the lower limit of the band. On the other hand the gradations of the samples from the section with good performance are nearly identical, all falling within the narrow range shown in Figure 4. This indicated that the poor performance is due to nonuniform support offered by the segregated subbase.

Segregation of subbase material during construction results in variations in density, moisture content and permeability. These may eventually cause variations in the density and moisture content of the subgrade soil, which adds up to possible damage to the pavement due to differential support. Therefore, a subbase with a fairly constant gradation will result in improved pavement performance. Reducing segregation to a minimum by careful handling and mixing during construction is well worth the effort.

Attempting to determine how a subbase was built after it has been in service for some time is a difficult task and often involves making assumptions which may not be true. To obtain more detailed information on the relationship of subbase construction methods and pavement performance, a series of special subbase study sections are being established throughout the country. At present 28 of these sections have been set up in nine states. The locations are shown in Figure 5. On these sections the subbase construction is closely observed, tests are made on the subbase and samples of subbase material are taken for laboratory tests. Thus the future performance of the pavement on these sections can be correlated with subbase construction methods.

These sections are on projects representing a wide range of climate, soil types and subbase design and materials. Routes that carry substantial volumes of heavy truck traffic were chosen in order that the performance trends can be established in a minimum length of time.

A 2,000-ft section of each project included in this study is selected to represent normal construction for that project. Every effort is made to see that these sections are built in the normal manner so that typical construction methods are being studied.

When the section has been fine-graded and all subbase work completed, the tests are made on the subbase just ahead of the paver. Density and moisture tests are made at frequent intervals and samples are taken at each test site for laboratory determination of gradation, plasticity index and to establish standard moisture-density curves. The test sites are staggered transversely so as to include the full width of the lane being studied. Additional tests have been made on several sections. These have included a full series of tests both before and after fine-grading, tests on the subgrade soils, a number of tests in small areas to determine the degree of uniformity, and field CBR tests. Complete written and photographic records of construction methods are made on each section.

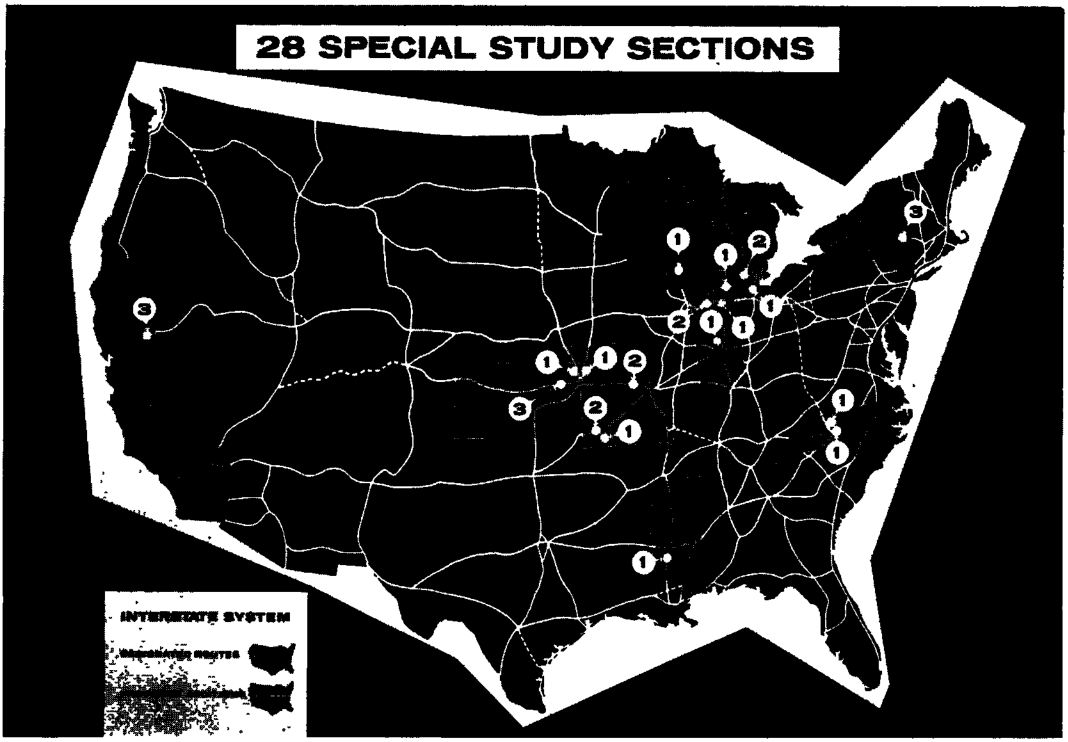

Figure 5.

Detailed pavement condition surveys are made on these sections periodically for a number of years until the performance trends have been established. The initial survey is made after paving and before the road is opened to traffic.

Since the oldest sections are located on projects built in 1954, definite performance trends have not yet been established. However, test results for most of the sections are available. They illustrate subbase conditions resulting from typical construction methods.

The uniformity of subbase density achieved from a given compactive effort depends to a large extent on the uniformity of subbase gradation. The prevention of segregation is extremely difficult for material with a very large maximum size. Figure 6 shows the large range of densities on a section with a bank-run gravel having a 4-in. maximum size. The wide band in Figure 7 represents the wide range in gradations of the subbase material on this section. The curves inside the band illustrate typical gradation variations between individual samples.

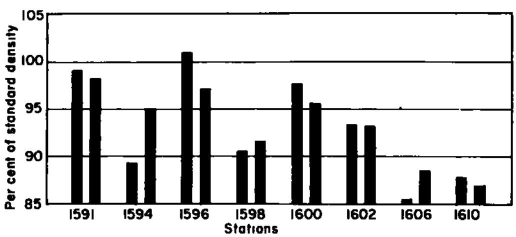

Figure 6.

Figure 8 shows the density test results for a section having a gravel subbase with a smaller maximum size. Densities are uniformly high except at Station 4179. The gradations of the samples from this section are practically identical, all falling within the narrow band in Figure 9, except at Station 4179 which was the location of the lower density. If all the material had the same gradation as that at Station 4179 the compactive effort and moisture content could have been adjusted to give uniformly high densities. However, since the material is different from the surrounding material, but received the same amount of moisture and compaction, the resulting density was different.

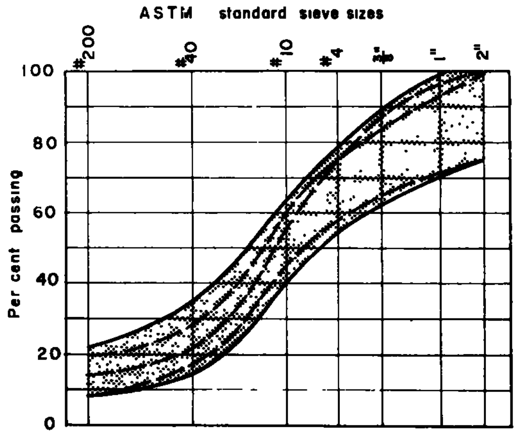

Figure 7.

Figure 10 shows uniformly high densities on a section where a similar material was used and the gradations of samples from this section (Fig. 11) are nearly identical, all falling within a narrow range.

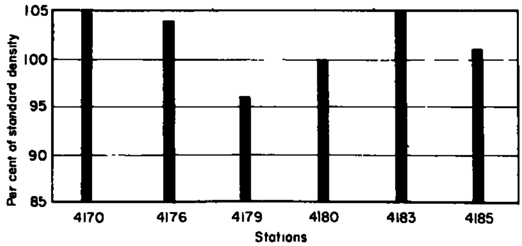

Figure 8.

SUBGRADE

If the subbase is to be compacted to a uniform density and provide uniform support for the pavement, it must lie on a uniform subgrade. Soft spots should be located by proof-rolling or other means, and then excavated and recompacted. If the soft spot consists of a pocket of soil which has sharply different properties from the surrounding soil, it should be replaced with the same type of soil as the adjacent subgrade. Even support cannot be obtained merely by dumping extra granular material on the soft spot as was done at the location shown in Figures 12 and 13.

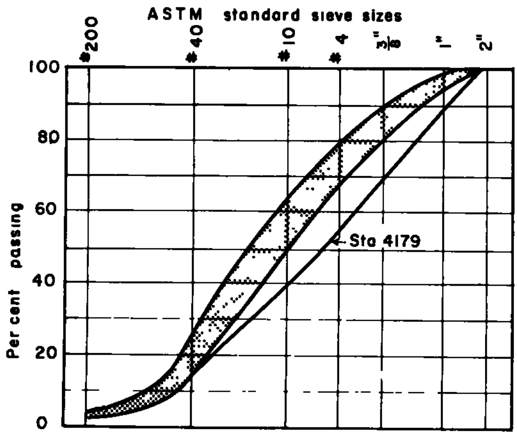

Figure 9.

One of the most important considerations in subgrade construction is moisture control. If the subgrade is too wet the subbase will be ground down into it during construction and construction traffic will cause rutting. If the subgrade is too dry, especially if it contains a significant amount of clay, it will become unevenly wet and soft during the first heavy rains after paving. The moisture content will in-

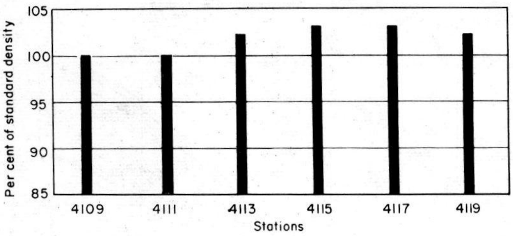

Figure 10.

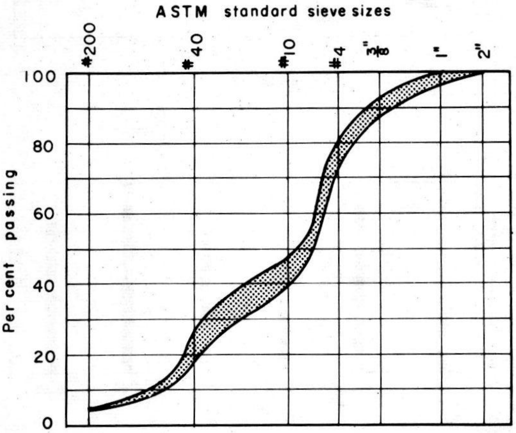

Figure 11.

crease more rapidly at the joints and at the pavement edges causing excessive softening at these locations, uneven support for the pavement and possible damage during its early life.

An example of this can be found in a group of projects with the same pavement and subbase design, built on similar soils and subjected to similar traffic, but in which individual projects are performing quite differently. Some of these projects were built during a period of prolonged drought and the subgrades were placed and compacted without adding water. The pavements have developed structural damage at an early age. The other projects in this group were constructed during periods of normal rainfall. They have no structural damage even though the pavements are older.

Soils containing appreciable amounts of clay will have the lowest permeability and retain the highest degree of stability when they are compacted at or slightly above the standard optimum moisture content (AASHO T99)[1]. Heavy clay soils tend to be somewhat rubbery at this moisture content, which sometimes causes difficulty in compacting an overlying thin layer of granular material to the required high density.

Figure 12.

Figure 13.

[1] In Highway Research Board Bulletin 58 "Compaction of Embankments, Subgrades, and Bases," page 12: "Soils compacted at optimum moisture content have lower permeability and a greater resistance to softening than dry soils at equal densities."

This problem has been successfully solved in many cases by the use of pan-type vibrators in compacting the subbase.

Subbase Moisture-Density

Granular subbases are susceptible to consolidation from vibration which occurs from traffic passing over the pavement. To reduce this consolidation to a minimum, the subbase should be compacted to as high a density as practicable during construction[2]. This is done most effectively when the material is at its optimum moisture content, which usually means that additional water will be required. In order to get uniform density this water must be thoroughly mixed into the material until it has a uniform moisture content. This mixing is also beneficial in reducing segregation.

When the water is added after the material has been spread on the grade, the mixing is effectively accomplished by the use of mortar graders or multiple pass type mixers. If the water is added on the grade and not mixed into the subbase, it will usually penetrate only about ½ in. even in fairly permeable materials.

The mixing of subbase materials and water in pugmills is becoming more widespread. The material is then placed evenly on the grade by aggregate spreaders. The slight additional cost of this method is often offset by the ease in placing and compacting the material.

Ten- to twelve-ton steel-wheel rollers are still extensively used for compacting subbases. They produce satisfactory densities on most granular materials except cohesionless sands. However, if the material has a large maximum size, these rollers tend to ride on the high spots, bridging and leaving loose material in the low spots. Rubber-tire rollers are effective in producing uniformly high densities by adjusting to uneven surfaces and local areas of loose material. They have a kneading action which knits the granular particles together into a dense mass. Heavy rubber-tire units weighing 30 to 50 tons or more have been used on some of the projects included in the special study section group. They are particularly useful in locating soft spots. Vibratory compacters, both the pan type and vibrating rolls, are now widely used to obtain high densities in many types of granular materials. Sometimes a combination of two types of compaction equipment is the most effective means of producing the required density.

FINE-GRADING

The difficulty in fine-grading increases as the maximum size of the subbase material increases. Pit-run gravel containing large stones is

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[2] In Highway Research Board Bulletin 58, page 24, the suggested range of densities for granular subbases for rigid pavements is 100-105 percent of AASHO maximum density when construction traffic does not use the prepared subgrade and 100-110 percent when construction traffic hauls over the prepared subgrade. In the paper "Performance of Subbases for Concrete Pavements under Repetitive Loading," by B. E. Colley and W. J. Nowlen, presented to the Highway Research Board in 1958, one of the conclusions of a laboratory study of the densification of granular subbase materials is that compaction to at least 100 percent of AASHO maximum density is required if densification under traffic is to be small.

Figure 14.

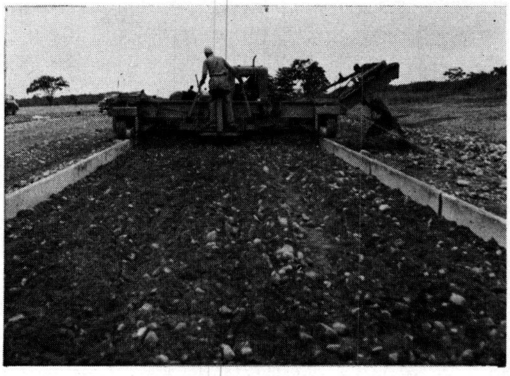

Figure 15.

particularly difficult to fine-grade. After the initial compaction of this type of material, the subbase often has to be loosened by scarification to a depth of about 4 in. and the larger stones near the surface must be removed by hand before the fine-grader can work on it (Figs. 14 and 15). After fine-grading, the large stones which have been brought to the surface have to be removed and the resulting depressions filled with finer material. With small-sized material, such as sand, fine-grading is often effectively accomplished by a motor grader or a tractor-drawn heavy straightedge riding on the forms.

The surface of the subbase is usually loosened and some loss of moisture occurs during fine-grading operations. Because of this, sprinkling and recompacting the top layer after fine-grading is required to restore uniform density to the full depth of the subbase. Generally the heavier compaction equipment is employed before the forms are set. After the surface has been disturbed by fine-grading, restoration of the initial high densities to the top 1 to 2 in. of subbase is often neglected.

When the full width of the subbase is left slightly high after initial compaction, the fine-grading is a cutting operation and the disturbance of the subbase surface and resulting variation in density, gradation and permeability is reduced. However, when the subbase is left high in the middle and low at the sides, variation across the width of the roadway is likely to occur since the edges are brought up to grade by filling in with loose material while the initial density is retained or increased in the center. This is especially true when the subbase immediately next to the forms is neglected during final compaction.

Final compaction is sometimes attempted by means of a series of small steel rollers attached to the rear of the fine-grading machine. This method does not always prove satisfactory in obtaining the required uniformly high densities in the subbase. The rollers are too light for effective compaction, and since they are attached to the fine-grader only one pass is made regardless of the density achieved.

One future maintenance problem associated with fine-grading is the handling of the excess subbase material. When a fine-grading machine is used the excess material is often deposited in a windrow just outside the side forms. If this material is not removed, or spread out and compacted during shoulder construction, it can lead to trouble at the pavement edge.

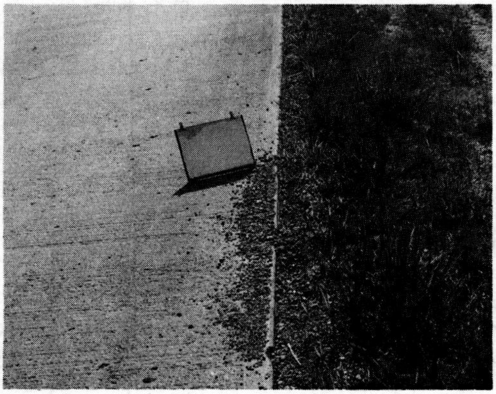

Figure 16.

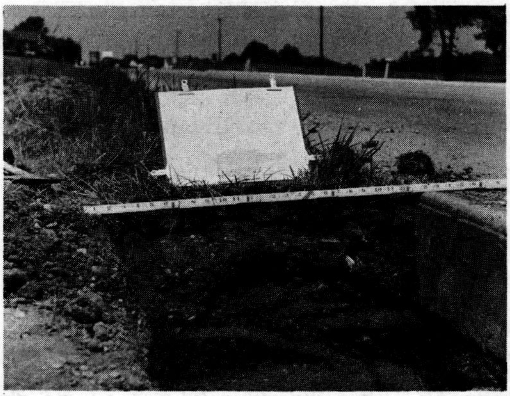

Figure 17.

Figure 16 illustrates one effect of water action which may occur when the windrow of excess subbase material is left in a loose condition during shoulder construction. Figure 17 shows the windrow exposed in a shoulder excavation at the same location. This excess material causes no problem if it is spread out and compacted. Some fine-grading machines deposit this excess material directly into trucks for re-use in another location.

One construction practice which makes it practically impossible to secure a uniform subbase is that of operating the paver between the forms. Not only does the paver tear up a well-built subbase, but the batch trucks necessarily drive over the completed grade. The batch trucks cause considerable rutting and segregation, particularly at turn-around locations and where the forms are removed for their entrance and exit as shown in Figure 18. In wet weather the trucks track mud onto the completed subbase. An example of this is illustrated in Figure 19. The batch trucks generally operate down the middle of the subbase, especially when they have to cross over the fine-grading machine. As a result this heavy traffic produces higher densities in the center of the roadway then the compaction equipment can achieve along the edges. This uneven density across the width of the roadway sometimes results in serious defects in the pavement, such as longitudinal cracking, due to differential support.

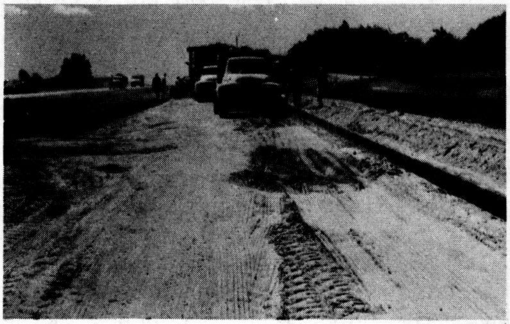

Figure 18.

Figure 19.

SUMMARY AND CONCLUSIONS

Uniformity is the key to building a subbase which will enable the pavement to retain its original smoothness for many years. To provide a uniform support for the pavement the subbase must lie on a uniform subgrade and have uniform density, gradation and permeability when the pavement is placed, and must be designed and built so that it will retain these uniform qualities throughout the life of the pavement.

The following construction procedures have been found to contribute towards providing uniform pavement support:

1. Selective grading and cross hauling results in more uniform conditions in the upper part of the subgrade.
2. Close moisture control during grading operations, keeping the compaction moisture content at or slightly above optimum (AASHO T99), provides a more uniformly stable foundation. When the subgrade has dried out before the subbase is placed, loosening of the top 6 in. followed by recompaction at the proper moisture content reduces damage due to differential support caused by uneven softening during the first wet weather after paving.
3. Proof-rolling by heavy rollers locates soft spots in the subgrade. Excavation and recompaction at these locations and replacing or mixing pockets of soil having dissimilar characteristics controls damage from differential soil volume changes.
4. The use of subbase material with a maximum size of about $1\frac{1}{2}$ in. or less reduces segregation and facilitates placement, compaction and fine-grading.
5. Thorough mixing of the subbase material in pugmills or on the grade reduces differential support due to uneven density, moisture content and permeability caused by segregation. By adding the required amount of water for effective compaction during the mixing operation, the moisture content will be uniform for the full depth and width of the subbase during compaction.
6. Compacting the subbase to the highest practicable uniform density reduces consolidation due to traffic vibration. Close moisture-density control is needed after fine-grading as well as before.
7. Realignment of forms which have settled during wet weather prevents variations in subbase thickness due to the removal of excessive amounts of subbase material during fine-grading.
8. Removing or spreading and compacting excess subbase material deposited along the edge of the pavement by the fine-grader reduces excessive water action at that location.
9. Mixing and recompacting a subbase which has been used as a detour or haul road restores the uniformity lost due to heavy traffic passing over the unprotected subbase. Keeping all traffic off the grade following final compaction insures that the benefits to be derived from good subbase construction will not be lost. It is practically impossible to provide uniform support for the pavement when paver and batch trucks are operated between the forms.

In the final analysis it is the combination of pride in workmanship, good inspection and a thorough knowledge of local pavement performance which has the greatest influence on improving the quality of construction and future pavement performance. A regular check of pavements both under construction and in service is the only way to determine what construction methods are best suited for overcoming problems which are associated with local conditions.