U.S. Department of Transportation
Federal Highway Administration

Hot-Mix Bituminous Paving Manual

MARCH 1985

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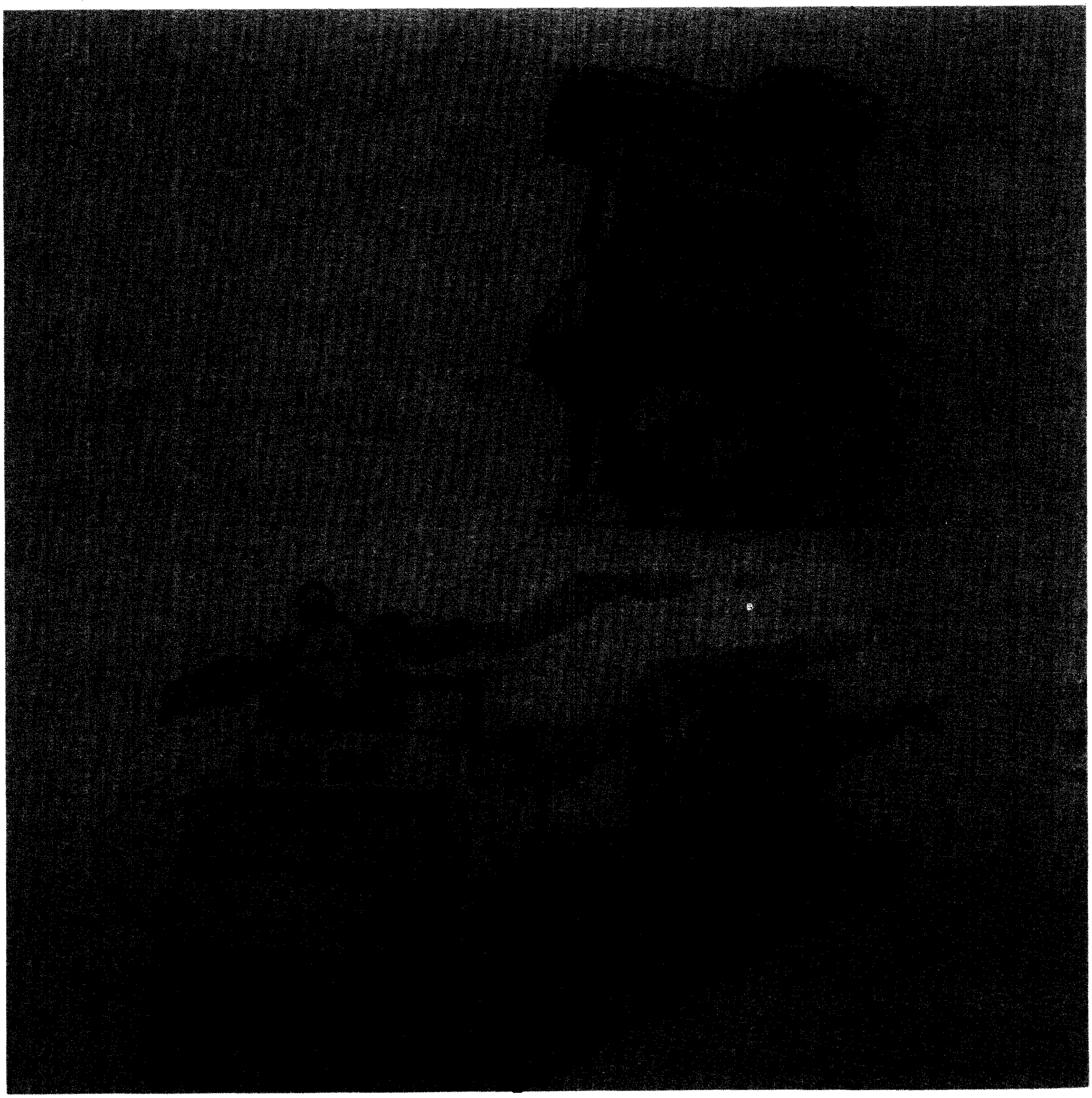

HOT-MIX BITUMINOUS PAVING MANUAL

Federal Highway Administration
Office of Highway Operations
Construction and Maintenance Division
Geotechnical and Materials Branch
March 1985

Acknowledgement

This manual was developed by the Geotechnical and Materials Branch of the Federal Highway Administration based on information and materials provided by Mr. W. H. Reynolds, of the FHWA Arkansas Division. Special appreciation is expressed to the FHWA Region 6 Office, The Arkansas Division Office, and to Mr. Reynolds for their support in the submission of the original information and in the assembly and refinement of the manual. Appreciation is also expressed to Ms. Annie Hamer and Ms. Angie Gregory for the cooperation and assistance in typing and editing the manual.

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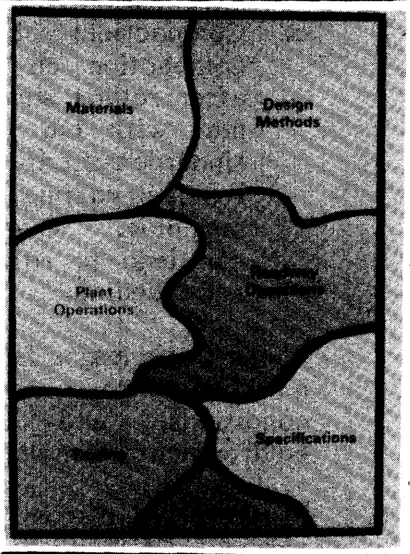
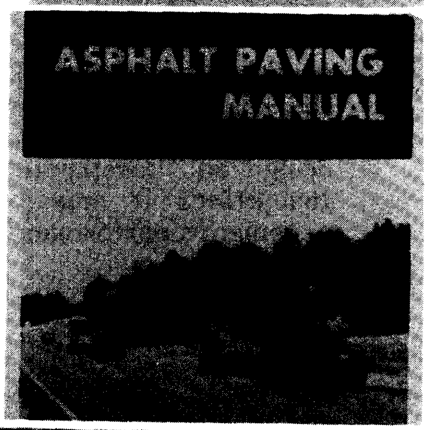
BITUMINOUS PAVING INTRODUCTION

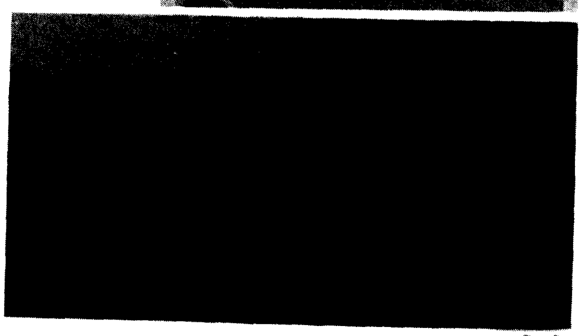
1. This training package has been developed to address the area of asphalt pavement construction. It includes as an introduction, the identification of some major pavement distresses. It then addresses the major phases of materials, design, production, placement, and compaction, then concludes with a more detailed look at asphalt pavement performance.



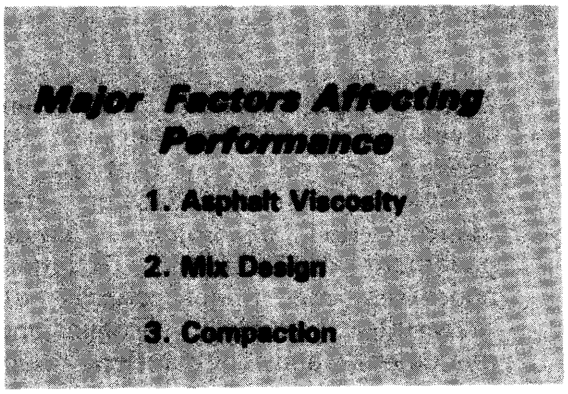
2. Many people, when thinking of asphalt pavements, tend to only think of the major phases independently. This presentation is intended to show the proper approach and considerations in each phase and also the interrelationships between the phases.



3. There are several sources of literature on these major phases. Two key sources are The Asphalt Institute publications and the National Asphalt Pavement Association publications.

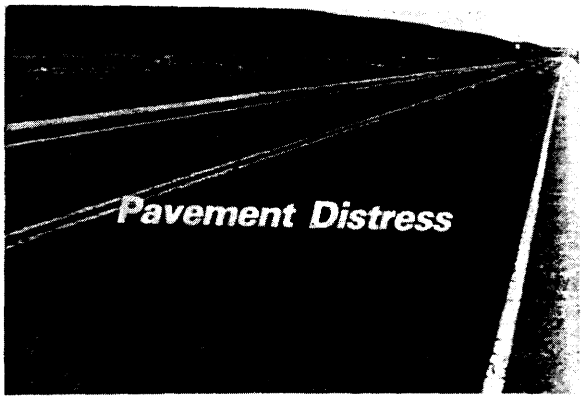


4. Once one gets involved and studies these publications one realizes that there are many factors affecting each major phase.

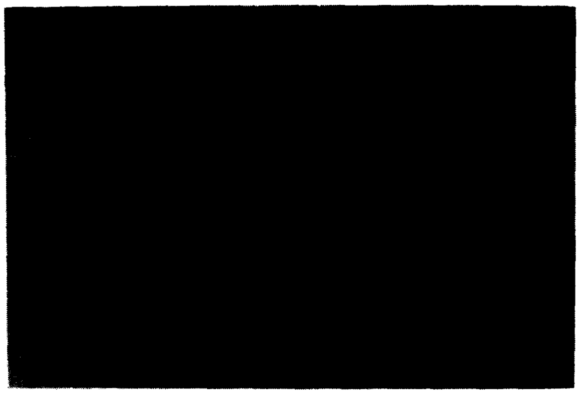


5. Major Factors Affecting Performance
   a. Asphalt Viscosity: Low viscosity may contribute to rutting and shoving, whereas high viscosity may contribute to cracking.
   b. Mix Design: In mix design we are concerned with obtaining a proper gradation and asphalt content to assure sufficient strength and a proper air voids system in the compacted pavement.
   c. Compaction: The degree of compaction on the roadway after rolling should produce a mat with 6% to 8% voids. Underdensification could result in rutting, cracking, and stripping. Overdensification can lead to rutting, shoving, and bleeding.

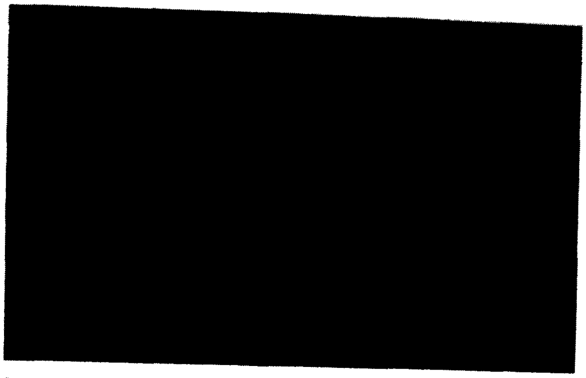
   These three major factors must be matched to the roadway conditions, and traffic and environmental conditions.



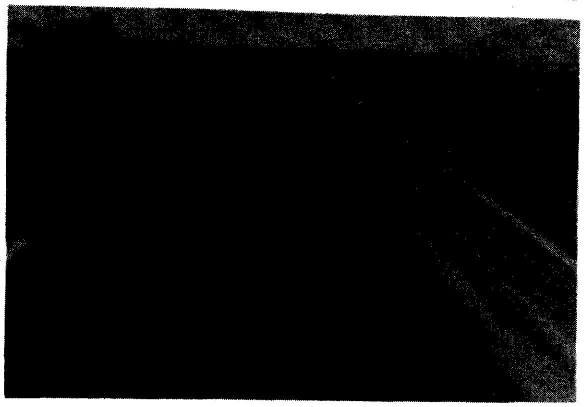
6. Before we discuss the various phases of mix design and construction of asphalt pavements, perhaps we should look at some of the distresses. We will then be able to relate each element of the design and construction phases to the effect it may have on the pavement's performance.



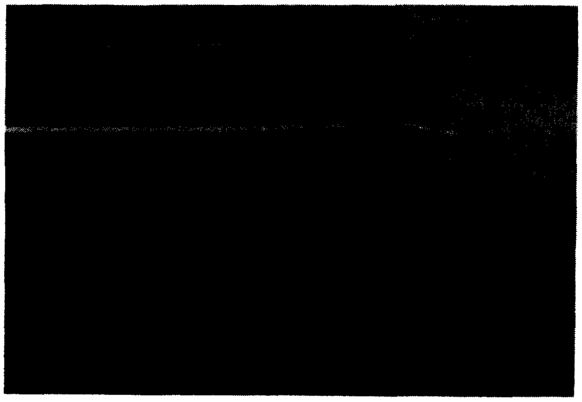
7. Ravelling: This is the separation of aggregate particles from the surface of an asphalt pavement.



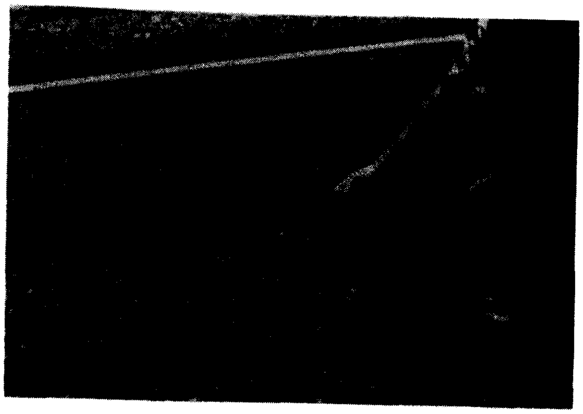
8. Bleeding: This is the presence of free asphalt on the surface of a pavement. It will result in extremely slippery pavement surfaces when wet.



9. Rutting: This is the longidutinal deformation that develops in an asphalt pavement under the action of channelized loadings (traffic).

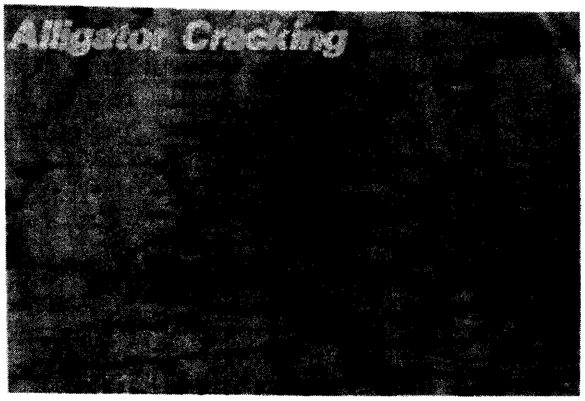


10. Shoving is the horizontal displacement of an asphalt mixture. It is usually associated with low stability mixes which under a horizontal thrust results in plastic flow. Also the mat can slip on the existing surface under a horizontal thrust. Shoving can occur at the connection of an asphaltic pavement to a rigid pavement or to bridge approach slabs. Shoving also may occur in interchange and intersection areas where horizontal forces from vehicular traffic is increased.



11. Stripping: Stripping is the breaking of the adhesive bond between the aggregate surface and the asphalt cement. Stripping occurs when water gets between the asphalt film and the aggregate surface. The asphalt is then displaced by the water or water vapor. Stripping may also result from the emulsification of the asphalt due to chemical inbalances.

    Stripping does not start at the pavement surface and proceed down into the pavement structure, but normally starts in an interlayer of the pavement structure.



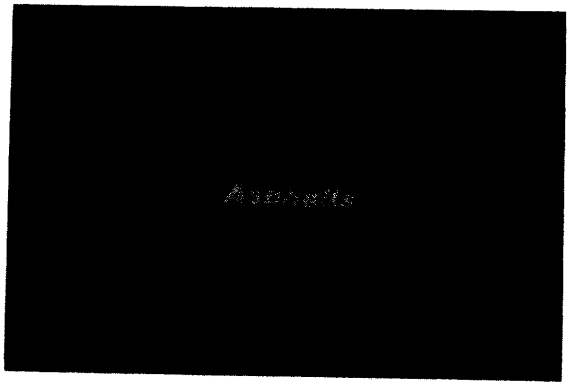
12. Cracking of an asphalt pavement is considered a normal failure mechanism. Premature cracking may indicate a mix design problem or a construction problem.

13. Unfortunately our mix design and construction procedures often build weaknesses into our pavements. Segregation, as shown here, can be a major factor in causing premature pavement distresses.

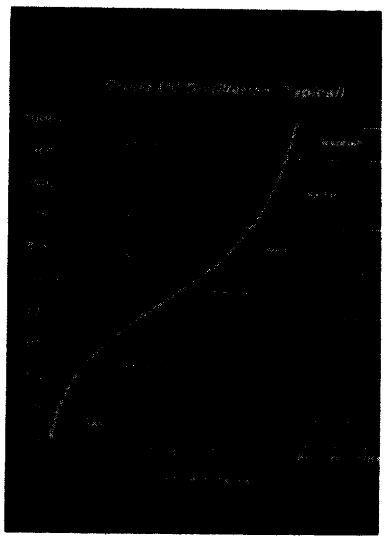
14. Having examined some of the major distresses of an asphalt pavement, the presentation will now go on to address the major phases as described previously. The presentation will attempt to show how the major phases are interrelated and further, their relationship to the pavement performance.

MATERIALS AND MIX DESIGN

1. This section of the presentation will cover the factors involved in the selection of materials and the concerns associated with proportioning them.

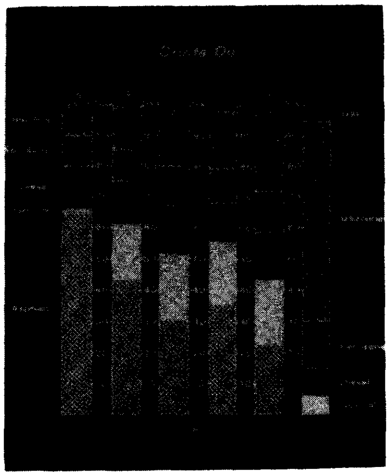


2. Asphalt is the first ingredient of the bituminous mixture that will be discussed. Virtually all of the asphalt used today in paving is produced by refining petroleum.

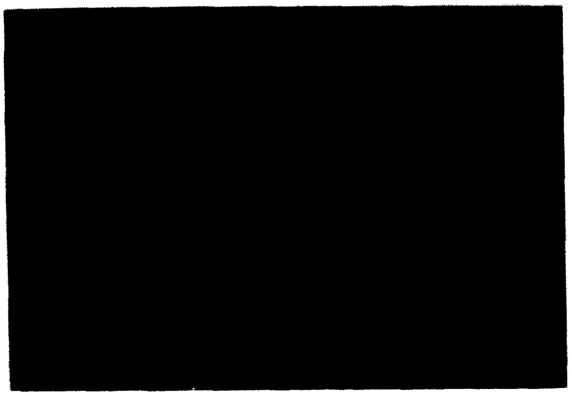


3. This slide shows a typical crude oil distillation with the distillation temperatures of the various products. The gas oils are removed in the temperature range of 700°F to 900°F and asphalts remain. The two processes by which asphalt can be produced from a crude petroleum are:
   a. The vacuum distillation process where heat and vacuum are applied, and
   b. The solvent extraction process where the gas oils are removed with a solvent leaving a residual asphalt.

   A specific grade of asphalt is usually produced from a particular crude source or blend of crude sources, or by blending different grades of refined asphalt.

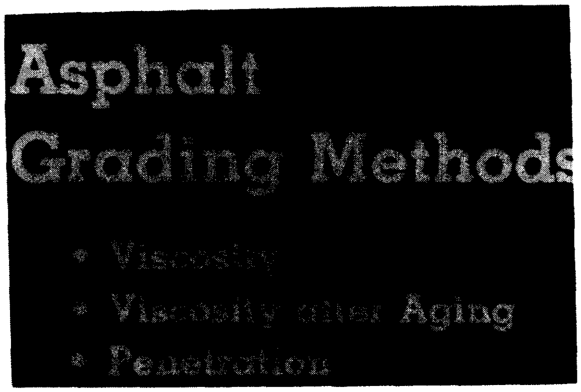


4. Crude petroleum sources vary from heavy crudes to light crudes. As shown in this slide, the percent of asphalt that can be produced varies from a high percentage from the heavy crudes to very little or no asphalt from the light crude. In some refineries asphalt is a substantial part of their production and therefore, they prefer the heavy crudes.



5. The following is a list of most of the tests conducted on asphalt.
   a. Penetration at 77^{o}F
   b. Viscosity at 140^{o}F
   c. Viscosity at 275^{o}F
   d. Flash Point
   e. Solubility
   f. Ductility
   g. Loss on Heating
   h. Penetration of Aged Material
   i. Ductility of Aged Material

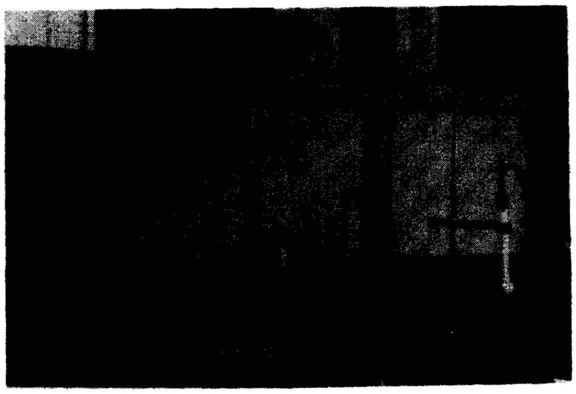
   Another valuable test not shown is the viscosity of aged material.



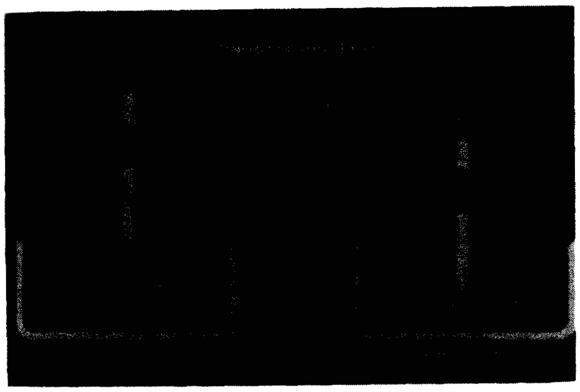
6. Asphalt cements are graded according to three different systems. The system most widely used is based on asphalt viscosity. In this system the flow of asphalt at 140^{o}F is measured and the asphalt is placed in a particular grade based on that flow.

Several western States grade asphalts according to their viscosities after undergoing an aging process.

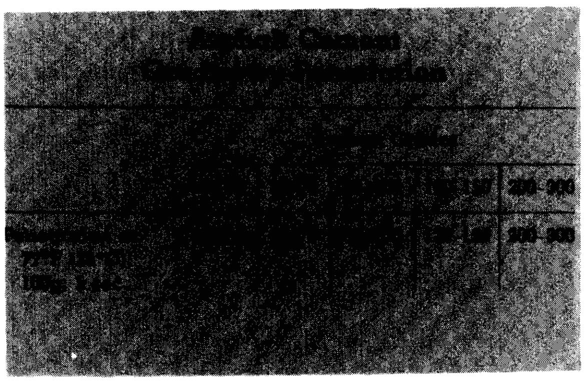
The third method of grading is by the penetration test.



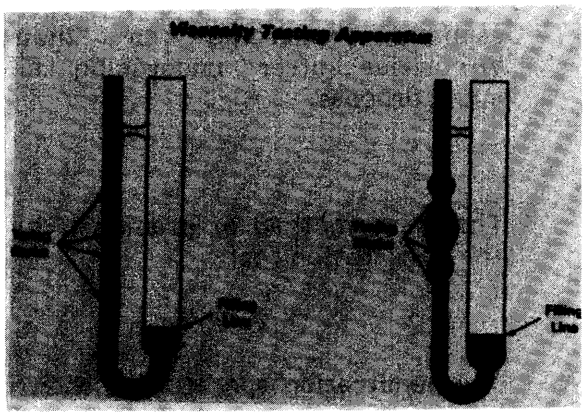
7. The penetration aparatus, as shown here, is used to determine the penetration value of the asphalt.



8. The penetration test is run on a sample of asphalt at 77°F. It measures the penetration (in units of 0.1 mm) of a standard needle with a 100 gram weight into the asphalt after 5 seconds.



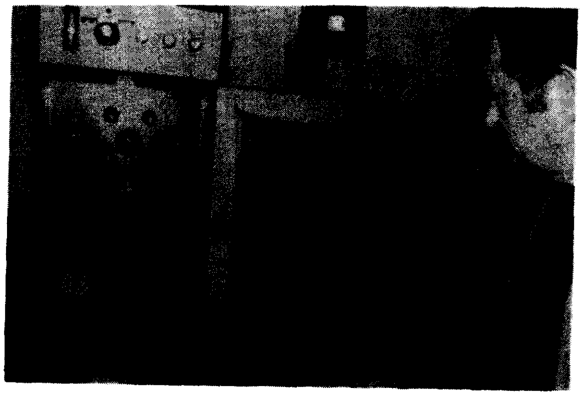
9. A 60-70 penetration asphalt is harder than a 120-150 penetration asphalt. Therefore, the harder the asphalt at 77°F the lower the penetration reading or value.



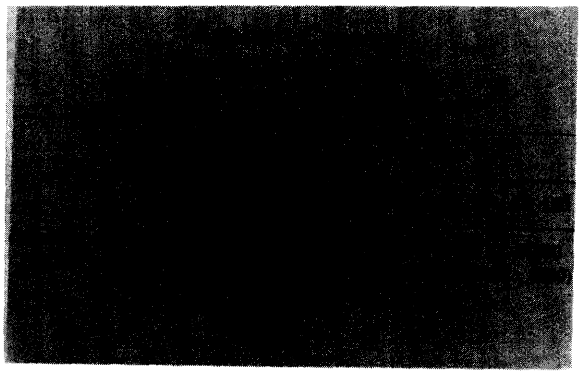
10. The viscosity test at 140°F uses a capillary tube viscometer, a calibrated glass tube to measure the flow of asphalt. The calibrated tubes are mounted in a temperature-controlled water bath, preheated to 140°F. The capillary tube has calibrated marks. As the asphalt begins to flow, its progress from one mark on the tube to the next is carefully timed. This measured time is then used to determine the absolute viscosity of the asphalt. Because asphalt at 140°F is too viscous to flow readily through the tube, a partial vacuum is applied to the small end of the tube to draw the asphalt through.

11. The viscosity test at 275°F is similiar to the 140°F test, except for the following:
    a. Clear oil is used in the bath instead of water because of the high temperature.
    b. The asphalt at 275°F is fluid enough to flow through the viscometer tube without the assistance of a vacuum.
    c. Because gravity and not a vacuum is used to induce flow, the viscosity is a kinematic viscosity.

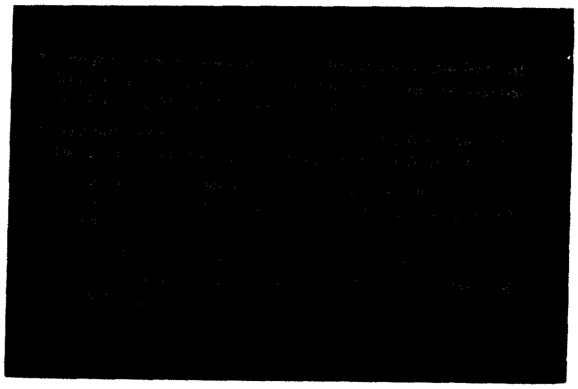
12. The viscosity grades are shown on this slide as ranging from an AC-2.5 to an AC-40 where the grade number is related to the viscosity at 140°F.



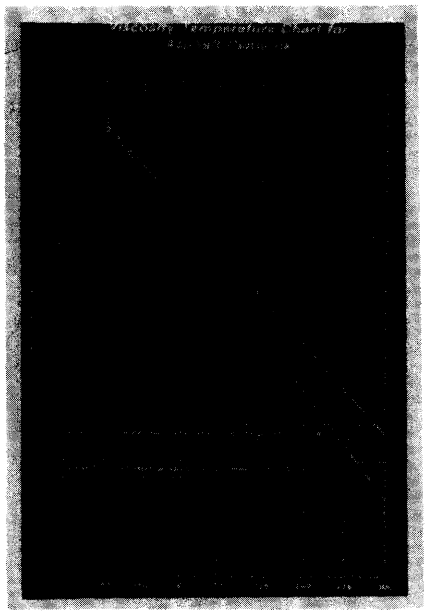
13. A third grading system used by several of the western states describes the asphalts according to their viscosity after aging. A standard aging exposure test in a laboratory oven is used to simulate aging in the asphalt plant during mixing. The asphalt residue that remains after aging is graded according to its viscosity in poises at 140^{o}F. The idea of this grading system is to identify what the viscosity characteristics will be after the asphalt is placed in the pavement.



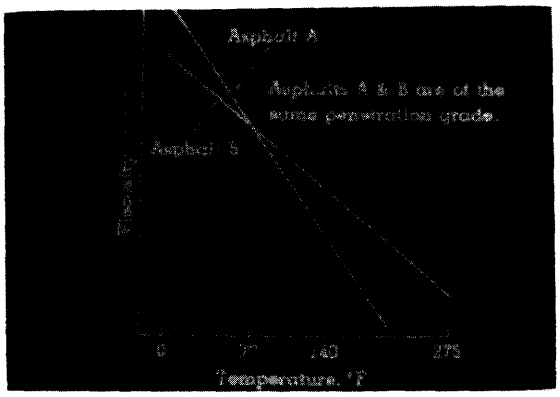
14. The asphalt grades designated as "AR" which stands for "Aged Residue," are AR-10 through AR-160. An AR-10 asphalt with a viscosity of 1,000 poises is referred to as soft asphalt while an AR-160 asphalt with a viscosisty of 16,000 poises is referred to as a hard asphalt.



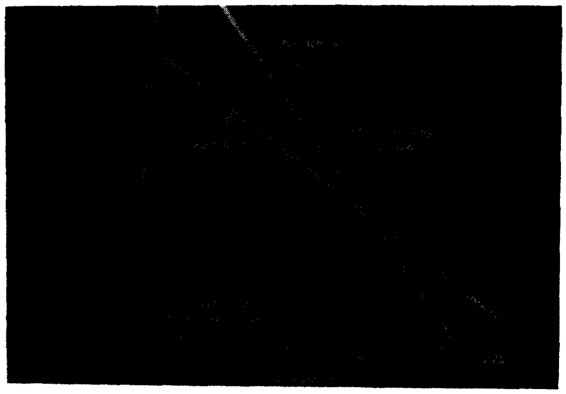
15. Temperature Susceptibility
Each particular asphalt has its own temperature-viscosity relationship. This relationship is sometimes described as temperature susceptibility. Changes in crude sources or blends of different crude sources will have their own particular temperature-viscosity relationship curve. These curves are very useful in determining the optimum mixing temperature and optimum compaction temperature of a particular asphalt.



16. Optimum Mixing Temperature and Compaction Tempertature
The optimum mixing temperature is that corresponding to a viscosity of 170± 20 centistokes. The optimum compaction temperature is that corresponding to a viscosity of 280± 30 centistokes. The temperature-viscosity curve can be used to determine the optimum mixing temperature range and the optimum compaction temperature range.

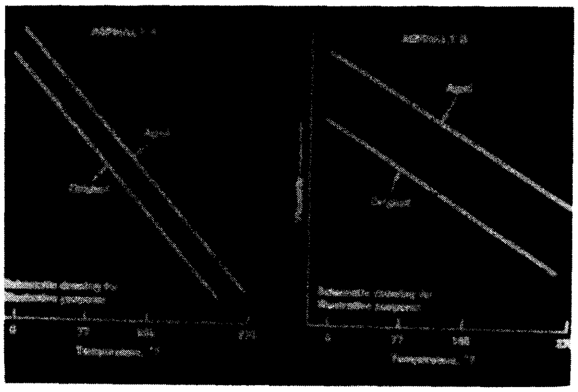


17. Temperature susceptibility is one of the asphalt's most important characteristics. However it is important to understand and recognize that temperature susceptibility in asphalts varies between different petroleum sources, even if the asphalts are identically graded. In this slide Asphalt A and Asphalt B are penetration graded asphalts with identical penetrations at 77°F, but are from different crude sources. Note the difference in their viscosities at the higher temperatures. Asphalt A will be more fluid than Asphalt B. This means that the temperature required to make Asphalt A fluid enough to properly coat all of the aggregate particles in the mix is lower than the temperature needed to get the same results from Asphalt B. The same is true for compaction temperature. It will probably be necessary to compact a mix with Asphalt A at a lower temperature than the same mix with Asphalt B.

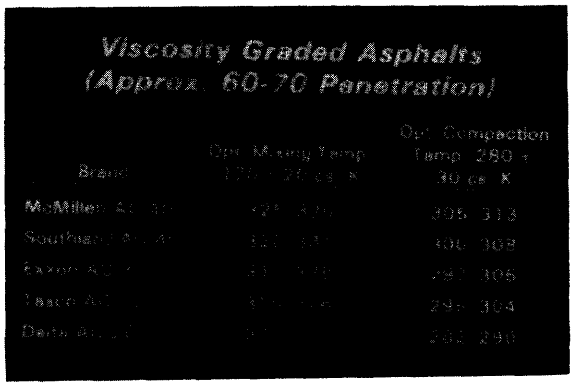


18. Same Viscosity
The same is true for viscosity graded asphalts. Here Asphalt A and Asphalt B have the same viscosity at 140°F, however, at all other temperatures their viscosities differ. As with the penetration graded asphalts, Asphalt A would probably require a lower mixing and compaction temperature than Asphalt B. Knowing the temperature susceptibility of an asphalt being used in a paving mixture is important because it indicates the proper temperature at which to mix the asphalt with aggregate and the proper temperature at which to compact the mixture on the roadway.

During the past 10 years a lot of construction and performance problems have been blamed on the asphalt. This may be true but before we place all of the blame on the asphalts, we need to look at the changes that have taken place during the past 10 years. Up until about 10 years ago all of the great majority of the refineries had fixed crude petroleum sources. Therefore, a particular grade of asphalt from a given refinery probably had very nearly the same penetration, viscosity, and temperature susceptibility. We in the highway industry learned to use these asphalts from fixed crude petroleum sources. During the past 10 years refineries no longer have fixed crude sources. They have new sources and are blending sources. The temperature susceptibility of asphalts from new and blended crude sources may be quite different from the asphalts made from the fixed sources we became accustomed to 10 years ago.

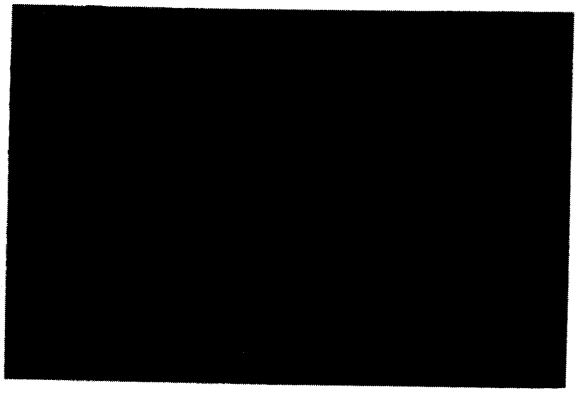


19. All asphalts tend to age or harden in the paving mixture during construction and in the pavement itself. The hardening is caused primarily by oxidation, when the asphalt combines with oxygen, a process that occurs most readily at high temperatures and when the asphalt is in a thin film. The most severe oxidation and hardening of the asphalt occurs in a batch plant process in the pugmill mixing when the asphalt is both at a high temperature and in a thin film as it coats the aggregate particles. The asphalt can also undergo severe oxidation and hardening in a drum mixer under certain conditions which will be discussed later in the section on asphalt plants. As indicated here asphalts from different sources age differently when subjected to a standard laboratory aging test.

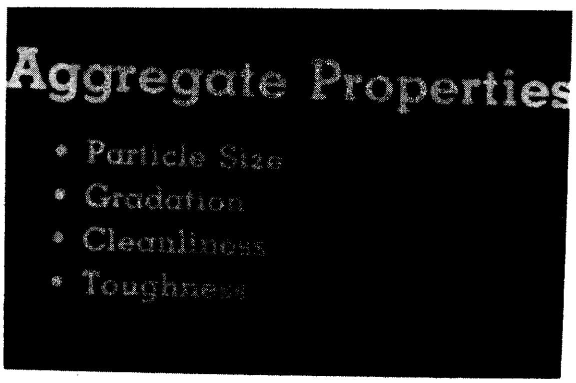


20. Arkansas Asphalts
There is no direct correlation between a viscosity graded asphalt and a penetration graded asphalt. Those states switching from the penetration grading system to the viscosity grading system may want to keep a maximum penetration or a penetration range to insure that they continue to get an asphalt with the hardness they are accustomed to working with. For example, the Arkansas State Highway and Transportation Department in switching to the viscosity grading system has tried to maintain an asphalt with a 60-70 penetration range. In order to

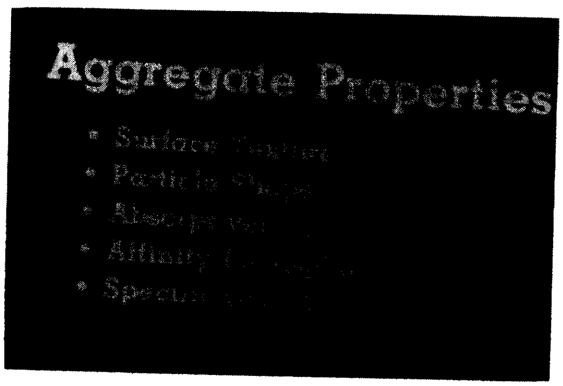
maintain this approximate penetration value, their viscosity graded asphalts vary from an AC-20 to an AC-40 grade asphalt depending on the particular refinery used. Note the difference in the temperature susceptibility of the asphalts from these various refineries as indicated by the differences in the optimum mixing and optimum compaction temperature ranges.



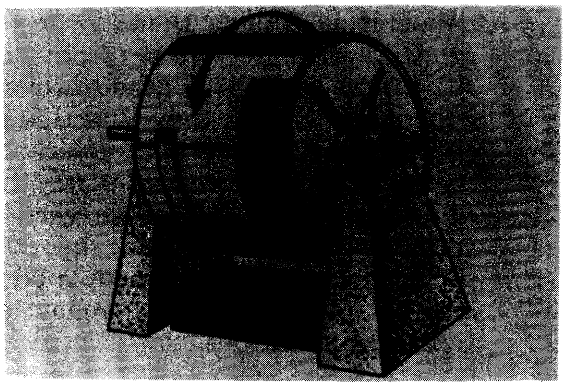
21. Ductility is a measure how far a sample of asphalt cement can be stretched before it breaks into two parts. This test probably represents the closest thing to a quality test that is performed on asphalt cements.



22. Aggregate is the granular material used in asphalt concrete. Aggregates make-up 90-95 percent of the hot-mix weight and provide most of the load bearing characteristics. Pavement performance can be greatly influenced by the use of proper aggregates. In order to determine an aggregate's suitability, its physical properties are tested as shown.



23. These physical properties must also be determined to properly design the mixture.

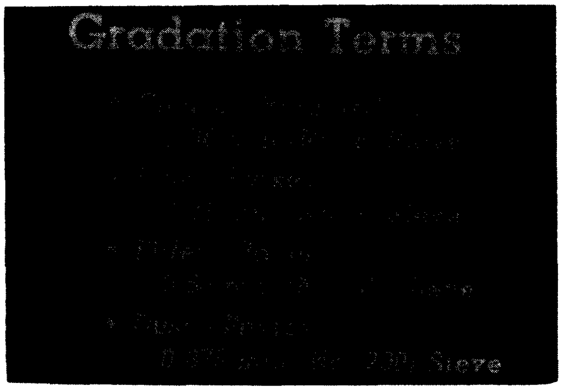


24. Aggregate cleanliness is usually considered by limiting the types and amount of soft or deleterious particles. Aggregates must be hard enough to resist abrasion and degradation during construction and under traffic. The Los Angeles Abrasion Test provides a measure of an aggregate's resistance to wear and abrasion.

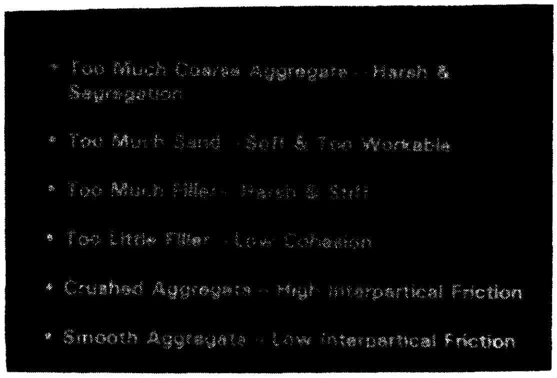
25. The shape of aggregate particles influence both the workability of the mixture and the strength of the pavement. Many agencies require a certain portion of the aggregate particles to have a fractured face.

26. The surface texture of an aggregate particle also influences the workability of the mix and the strength of the pavement, but in addition it influences the skid resistance of the pavement surface.

27. Aggregate gradation is probably the most easily altered or controlled physical property and it has a major effect on the mix. By separating the aggregate particles by their size and then recombining them selectively, a combination can be found that will allow sufficient voids to accommodate the proper asphalt film thickness on each particle, and still allow sufficient air voids to provide for thermal expansion of the asphalt and mix particles.



28. For a description of processed aggregate the terms as shown on this slide are used.



29. Some of the effects of aggregate gradation on the mixture have been determined by experience as follows:

   a. Too much coarse aggregate produces a harsh mix which tends to segregate easily.

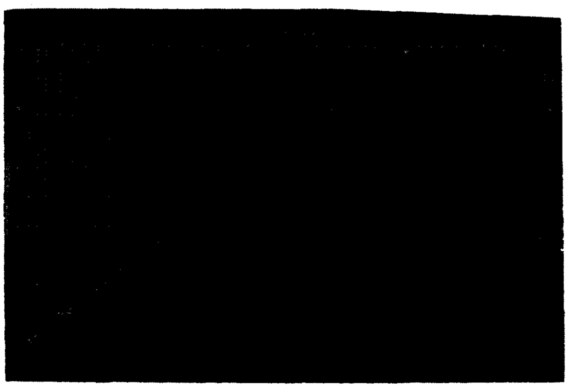
   b. Too much sand produces a soft mix which becomes too tender to properly compact.

   c. Too much filler produces a harsh stiff mix.

   d. Too little filler produces a mix with low cohesion.

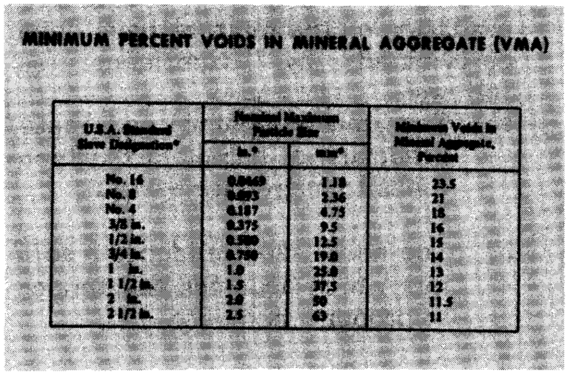
   e. Crushed aggregate produces a mix with high interparticle friction.

   f. Smooth aggregate produces a mix with lower interparticle friction.



30. In this gradation chart developed in the early 1960's by the Bureau of Public Roads, the sieve sizes have been raised to the .45 power. On these charts the maximum density line is determined by drawing a straightline from the bottom left corner of the chart through the 95% passing point or the first sieve containing material. The maximum density line is used to analyze the gradation of a particular mix. Usually a gradation following the maximum density line or very near the maximum density line produces high stability but low void mixes.

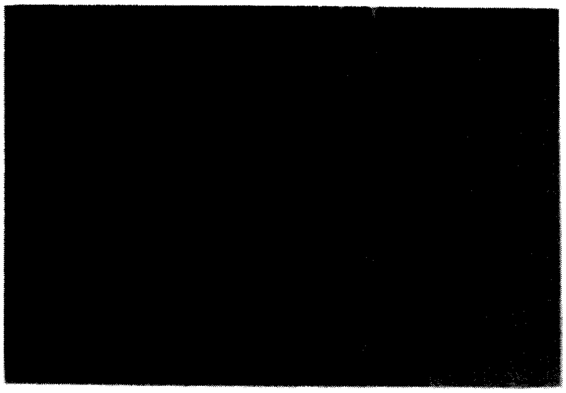
31. The real purpose in establishing and controlling aggregate gradation is to provide and maintain a proper void content in the aggregate. This is called voids in the mineral aggregate or VMA and is illustrated in this slide.



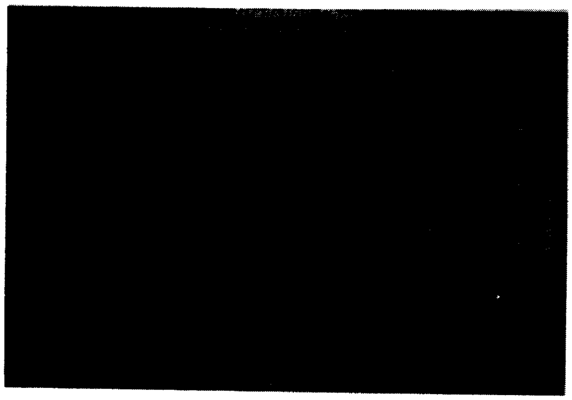
MINIMUM PERCENT VOIDS IN MINERAL AGGREGATE (VMA)

U.S.A. Standard Sieve Designation*	Nominal Maximum Particle Size		Minimum Voids in Mineral Aggregate, Percent
	in.*	mm*	
No. 16	0.0469	1.18	23.5
No. 8	0.093	2.36	21
No. 4	0.187	4.75	18
3/8 in.	0.375	9.5	16
1/2 in.	0.500	12.5	15
3/4 in.	0.750	19.0	14
1 in.	1.0	25.0	13
1 1/2 in.	1.5	37.5	12
2 in.	2.0	50	11.5
2 1/2 in.	2.5	63	11

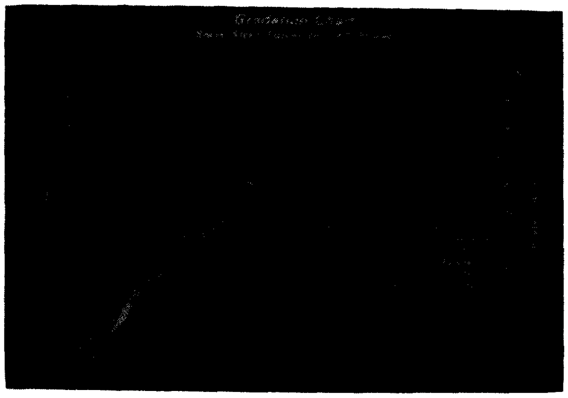
32. The VMA must be large enough to allow each particle to be coated with asphalt and still maintain a proper air void content in the final compacted mix. Minimum VMA requirements vary directly with top aggregate size.



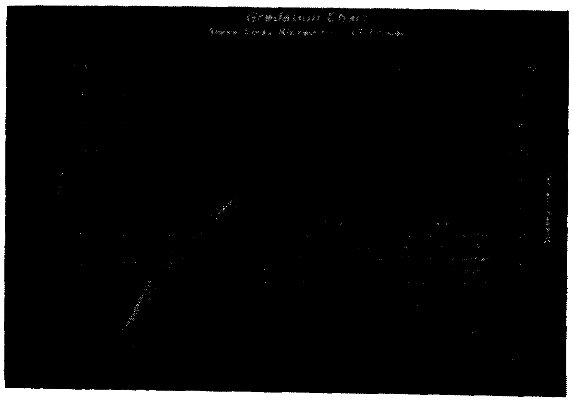
33. Air voids in the final compacted mix, after about three summers under traffic, should be 3-5%.



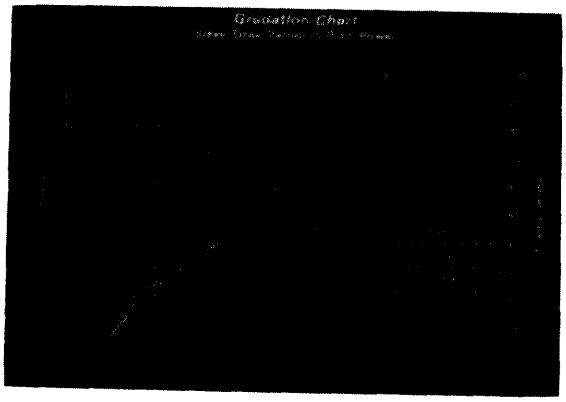
34. The maximum density line can also be used as a guide to adjust the mineral voids and the air voids of the mix. The more the slope of the mix gradation varies from the slope of the maximum density line the more mineral aggregate voids are provided in the mix. In some materials, especially limestone mixes, gap grading may be necessary to provide adequate voids. In verification and investigation of the gradation chart during its development, a series of gradations and mixes were made up and tested. Note in this slide that curve 3 of the maximum density line provides the lowest voids in the mineral aggregate while curves 1, 5, and 6 provide the highest voids.



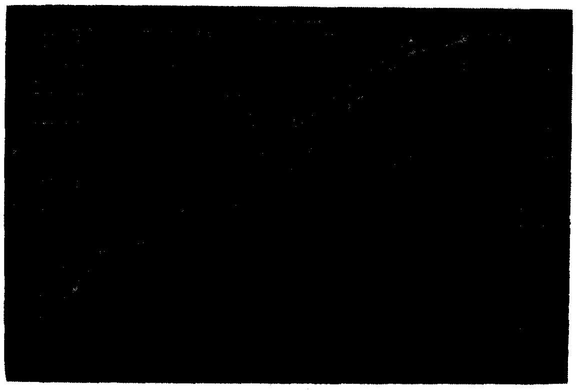
35. Note on this chart that curve 10 is closest to the maximum density line and provides the lowest voids and highest stability while curve 7 provides the highest voids but lowest stability.



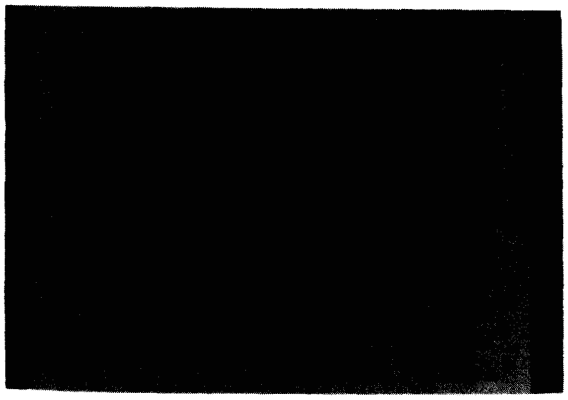
36. In these finer mixes, note that curves 15, 16, and 17 very nearly follow the maximum density line to provide the lowest voids and highest stability while curves 13, and 14 provide high voids but low stability.



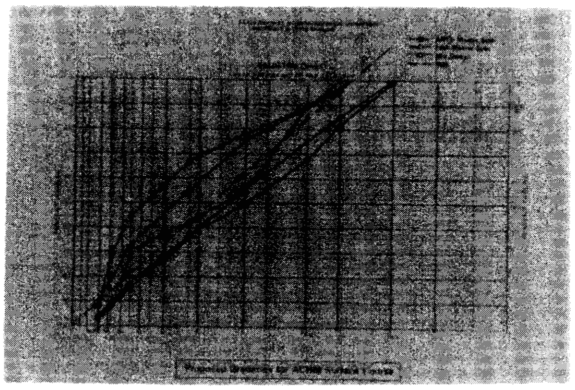
37. In these coarser mixes, note the same is true with respect to the voids and stability.



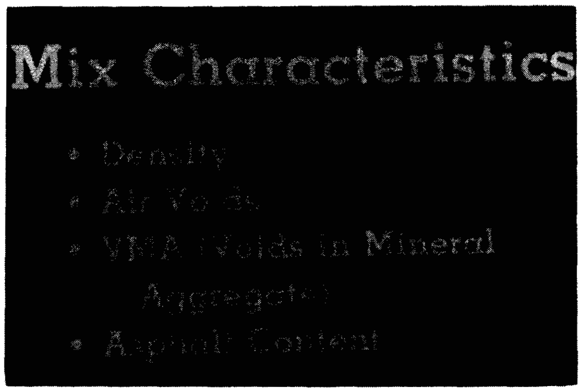
38. Upon development of the .45 power gradation chart, several problem mixes were studied to see if this chart could be used to identify the problem. This slide shows the gradation of one of the mixes that was identified as tender in the field during construction. These tender mixes will generally be identified by the hump near the #30 sieve.



39. Arkansas Mix Design
This slide shows two typical gradations used in Arkansas. Gradation A is a fine mix, gradation B is a more coarse mix. The fine mix is subject to less segregation. Note in both mixes the excess material between the 10 and 40 sieves. This material aids in field compaction.



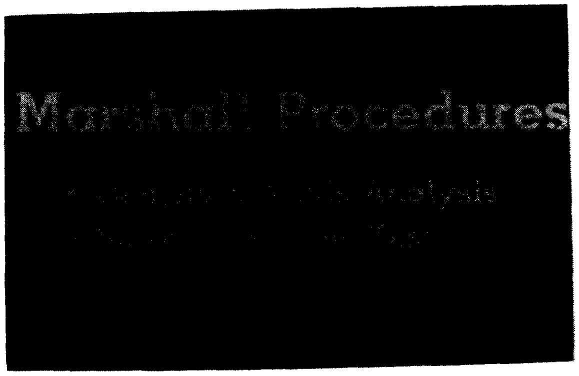
40. This gradation of aggregate was proposed for use as a surface mix. Note that the shape of the curve, although within specification limits, mirrors the typical tender mix curve.



41. Having discussed the main ingredients of a mix, we will now redirect the discussion to the mixture itself and its characteristics. These four characteristics will be addressed as they are most critical to the mix's performance in the pavement.
Density or unit weight is determined to establish target compaction values in the field and to ensure a proper air void system in the mix.
An air void's determination is conducted to assure space for thermal expansion and additional in-place densification under traffic.
The VMA is determined as previously described.
The asphalt content is established for the mix to provide sufficient coating of aggregate particles.

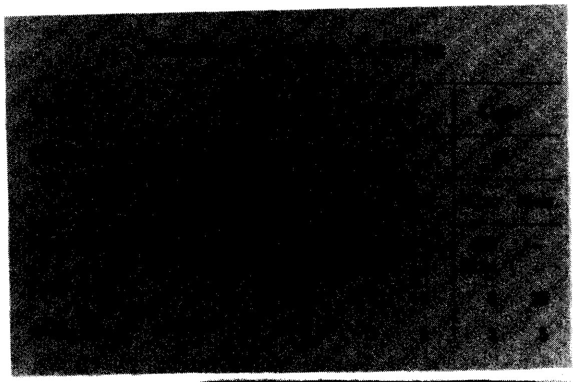
Another critical mix characteristic, although not shown on this slide, is moisture susceptibility. The effect of moisture on some asphalt/

aggregate combinations is extreme stripping. This effect should be evaluated as part of the mix design procedures for all mixes. Current methods subject mixtures or compacted specimens to water soak, freeze/thaw, and/or boiling conditions.

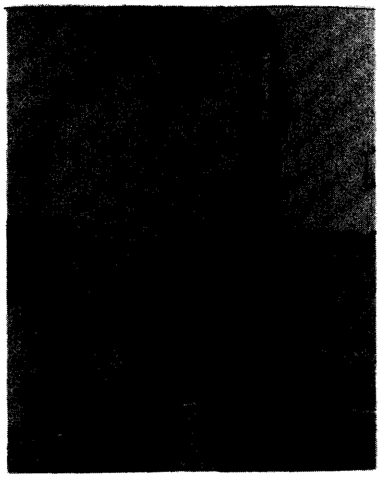


This presentation will discuss briefly the two most commonly used methods of mix design, the Marshall Method, and the Hveem Method.

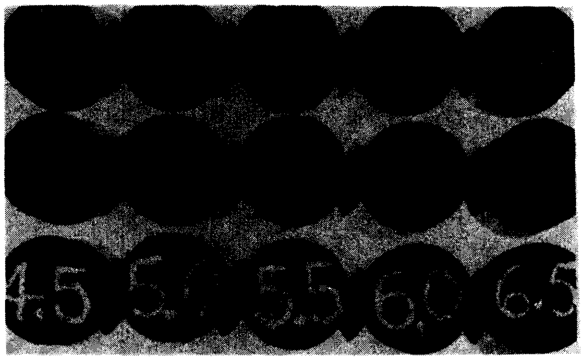
42. The Marshall Method of Mix Design consists basically of two procedures, a density and voids analysis of samples containing various proportions of asphalt and aggregate, and a measurement of the stability and flow under specific loading conditions.



43. Test specimen compaction requirements and design criteria for each mix is determined based on the traffic volume on the pavement.

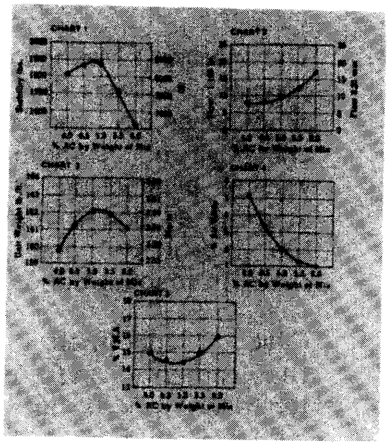


44. Specimens are then made up and compacted as shown.

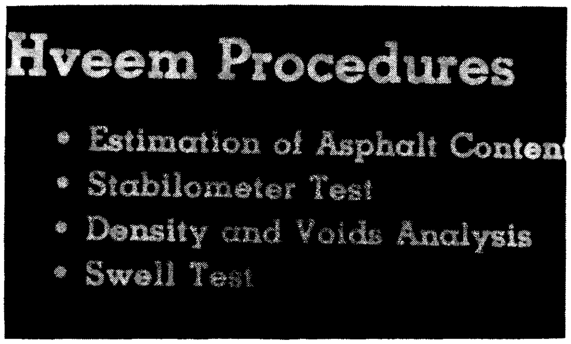


45. Three specimens make up one set and usually five sets are made at varying asphalt contents.

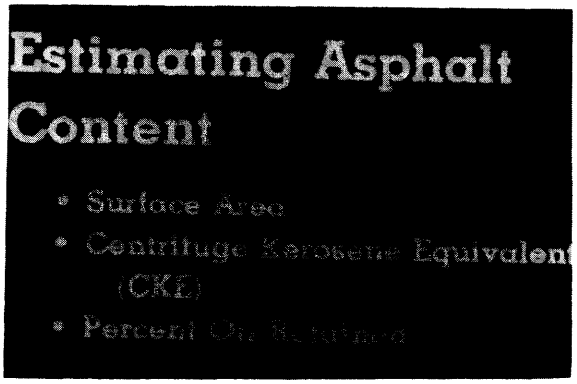
46. The specimens are then tested for stability and flow. This measures both the mixture's ability to handle loads and amount of deformation under specific loading conditions.



47. The results of the testing are then plotted on charts as shown and an optimum asphalt content selected.

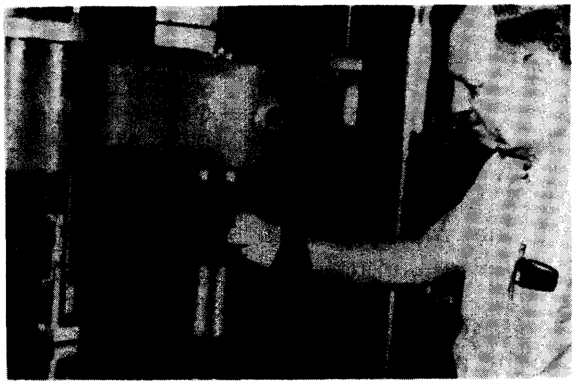


48. The Hveem Method consists of procedures to estimate the asphalt content, to determine the stability of the mix, to identify the density and voids of the mix, and to determine the mix's susceptibility to swell.

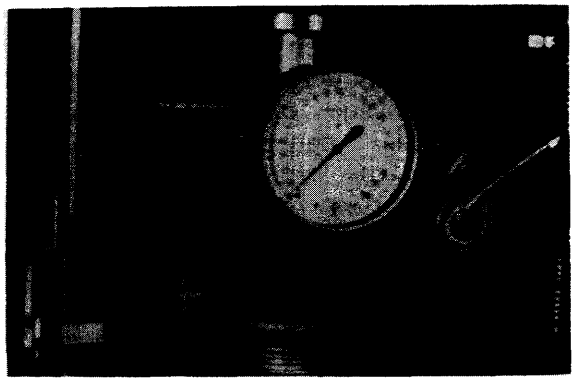


49. The asphalt content of the mix is estimated based on the surface area of the aggregate blend and a centrifuge kerosene equivalent for the fine aggregate. Computation charts are then used to determine the estimated asphalt content to prepare trial mixes for testing.

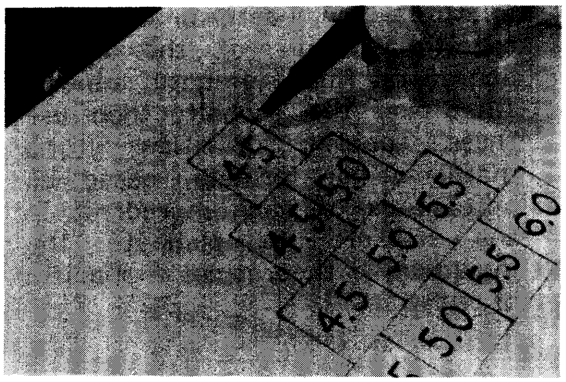
50. The trial mixes are made up and compacted by using a kneading compactor as shown.



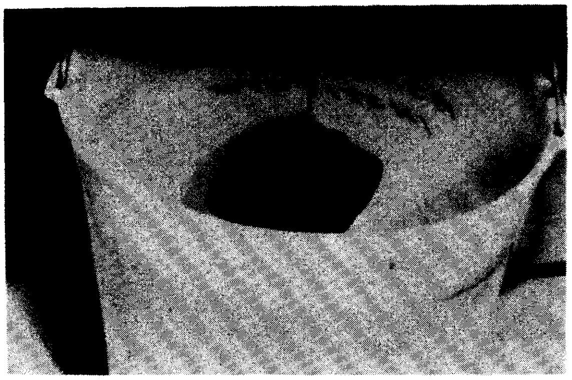
51. The specimens are then compressed as shown to level off any marks left by the compactor.



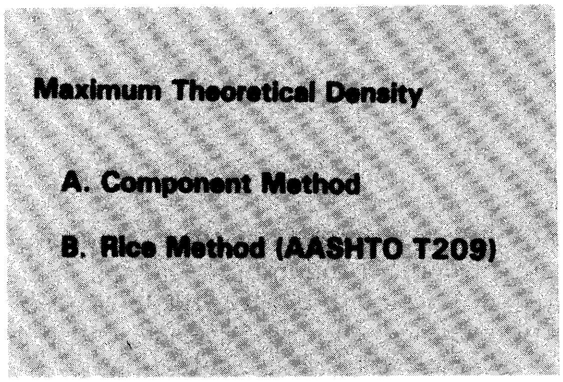
52. The specimens are then tested in a Hveem stabilometer as shown to determine the specimen's stability value. A swell test is also conducted to determine the amount of water a specimen can absorb and the amount of swelling this absorption causes.



53. The optimum asphalt content is then selected using a pyramid chart, the test results, and a visual examination of the test specimens.

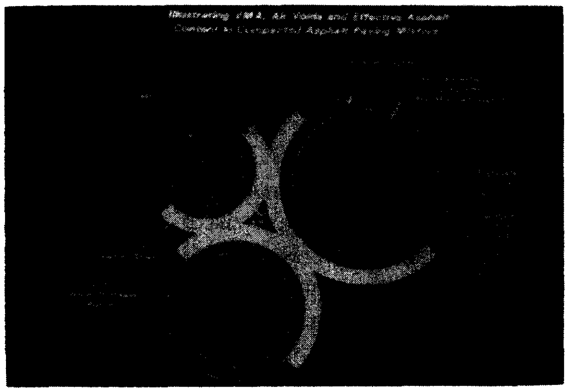


54. Regardless of the mix design procedure used, it is essential that the density and voids analysis be understood. Densities or unit weights are used during compaction to control the rolling operations and more importantly to assure a proper air voids system in the mat. The density of the laboratory specimens is determined and air voids calculated. This requires a determination of the maximum theoretical density of the mix.



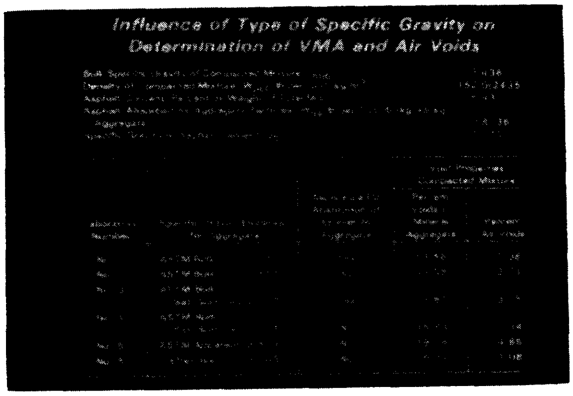
55. The method used in determining the maximum theoretical density of the mixture can have a significant effect on the density of the mat in the field. It is essential that we obtain a true 6-8% voids in the mat after compaction and before it is open to traffic. Since the roadway density is expressed as a percentage of the maximum theoretical density or specific gravity of the mixture, the determination of the theoretical maximum density or specific gravity is the key to determining the true air void content of the compacted mat. Most highway agencies determine the maximum theoretical specific gravity of the mixture by determining the specific gravity of the coarse aggregate, fine aggregate, mineral filler and the asphalt, then use these specific gravities in a mathematical formula, based on percentage of each ingredient in the mixture to compute the maximum theoretical specific gravity.

The Rice Method (AASHTO T209) utilizes vacuum saturation to determine the maximum theoretical specific gravity of the combined mixture.



56. Specific Gravity Determinations
When using the component method it is important that you understand which specific gravity is being determined and what that specific gravity means in terms of absorption. This diagram illustrates the difference between bulk specific gravity, effective specific gravity and apparent specific gravity. In this diagram the space between the coated aggregate represents the air voids. The white band surrounding the aggregate represents the asphalt. The hashed ring around the aggregate represents the absorbed asphalt. The speckled ring represents the voids filled by water but not filled with asphalt. And finally the dark center core represents the solid aggregate volume. The voids in the mineral aggretate, VMA, represents the voids between the aggregate particles and depending on the method used to determine the specific gravity, the voids within the aggregate particles. The air void content is that area of the VMA not filled with asphalt. If the apparent specific gravity is used, all voids filled with water are accounted for. However, the voids filled with water will not all be filled with absorbed asphalt and the mixture in the field could be a little high in asphalt content and low in air voids. If the effective specific gravity is used, the aggregate voids absorbing asphalt are accounted for. This method should account for the true void content of the mixture in the field. Many people believe the Rice

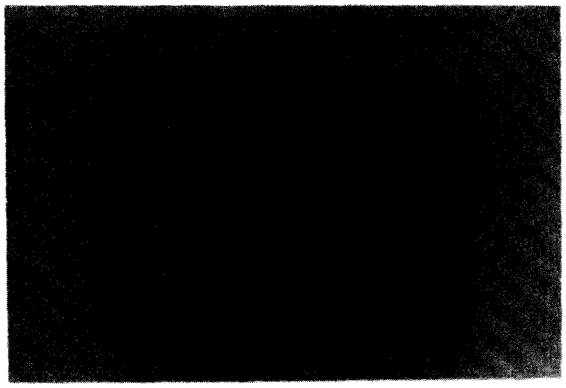
Method most nearly makes this determination. If the bulk specific gravity is used, then neither the voids absorbing asphalt nor the smaller voids absorbing water are accounted for. If asphalt is absorbed into the aggregate, then the mixture in the field would tend to be low in asphalt content and high in air voids. Therefore, it is important that one know which method is being used for determining the specific gravity and what that particular specific gravity means in terms of maximum theoretical specific gravity or density, VMA, and air voids. It is believed, that the Rice Method (AASHTO T209) is the most accurate method of determining the maximum theoretical specific gravity of a bituminous mixture and in turn the true air voids in the mixture.



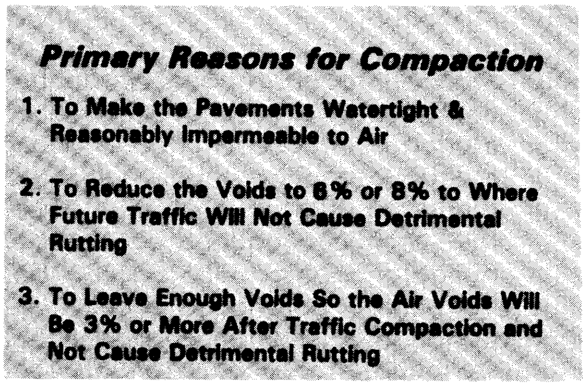
57. Influence of the Type of Specific Gravity on Determination of the VMA and Air Voids

This table illustrates the influence of 6 different types of specific gravity on the determination of the VMA and air voids. The bulk specific gravity of the compacted mixture is 2.436. The density of the compacted mixture is 152 lbs per cubic foot. The asphalt content expressed as a percent by weight of the total mixture is 5.93.

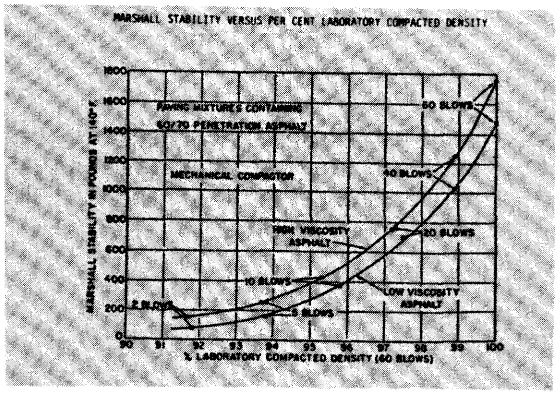
The asphalt absorbed by the aggregate particles is 0.8, and the specific gravity of the asphalt cement is 1.011. Note the change in the void properties of the compacted mixture for the 6 different methods. The percent air voids vary from a theoretical -0.73% to 4.85%.



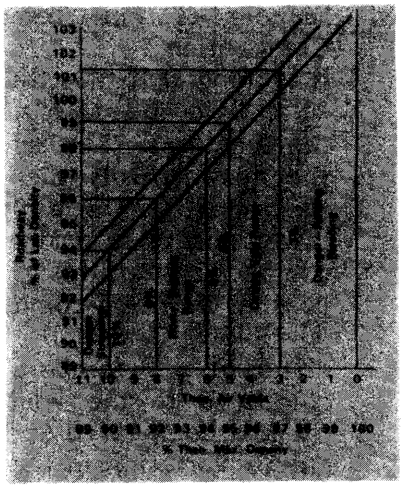
58. Effects of Mix Temperature of Compaction
It is important that the mixing and compaction be done at the proper temperatures. The temperature of the mix controls the viscosity of the asphalt. The asphalt must be in a liquid state during mixing and compaction. In this graph the void content in mixes compacted by the 50 blow Marshall method at different temperatures is compared to the void content of the mix compacted at 275°F. With only a variation in the compaction temperature note the difference in voids of the compacted mixes. Voids of 5% are attained at 275°F, but the voids have increased to 15% at 175°F. When the mix is compacted at 200°F the void content is 12%. In this particular mix, if the voids are to be under 10% it is necessary to compact this mix before it reaches a temperature of 200-225°F.



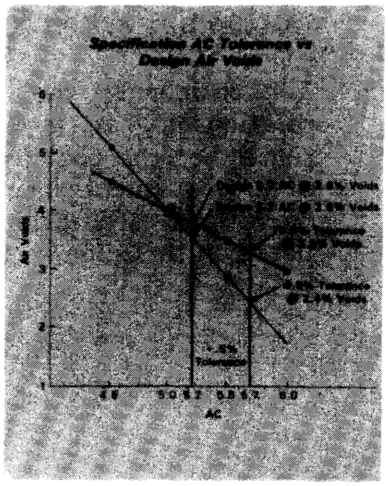
59. In considering the density/voids relationship, it is important to remember the goal for compaction of the pavement during the rolling operations. The primary goals are listed on this slide.



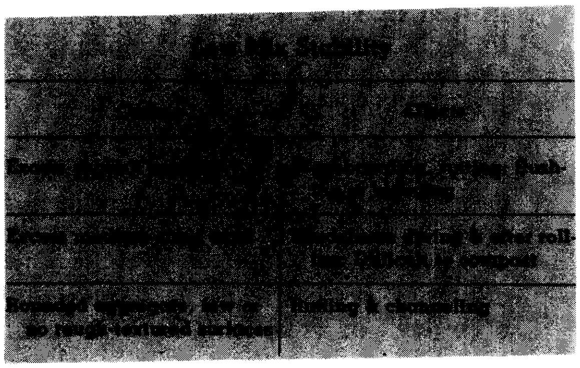
60. Stability vs. Density
In addition to making a pavement impermeable, another primary reason for compaction is to give the mix stability. As the density of a mix decreases from lab compacted density, the stability decreases also. This effect can be seen in this slide for a given mix. A compaction level of 97% of lab density results in a Marshall stability of about 40% of the stability of the mix when compacted to 100% lab density.



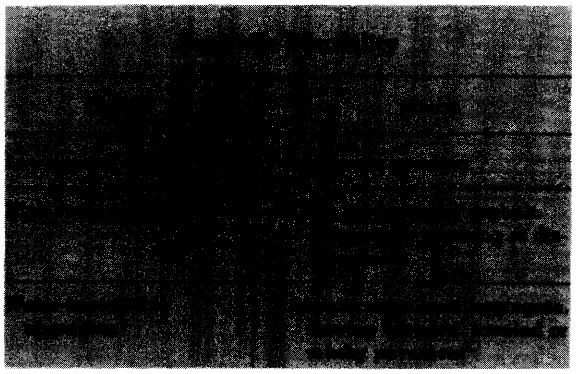
61. Void Range
We attempt to design a high performance mix with 3 to 5 percent voids as shown in the design void range area. We attempt to compact the mixture to a true 6 to 8 percent voids on the roadway. This will allow for additional compaction under traffic which will reduce the void content of the mat but keep it out of the 3 percent or less voids as shown in the area on the right side of the slide. When the roadway pavement gets to 3 percent or less voids, rutting and/or bleeding can be expected. Likewise we want to stay out of the zone which is above 10 percent air voids. This area would be considered under- compacted and will result in additional consolidation under traffic. This could also result in high void content which accelerates oxidation of the asphalt, allows the entry of water into the pavement structure, and may contribute to stripping.



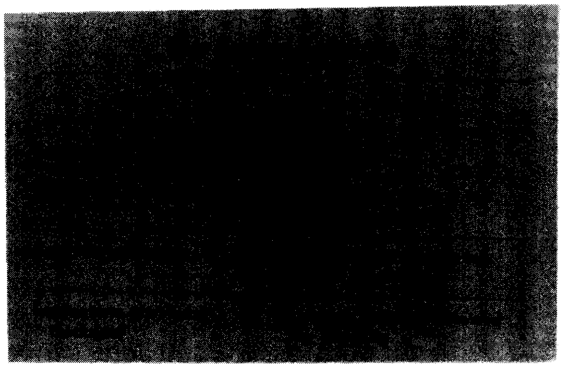
62. Another factor to consider in the voids content is its relationship to asphalt content. Most specifications include a tolerance range for asphalt content. When the optimum asphalt content is selected during mix design, the allowable tolerance should be added to it and the corresponding air voids determined. This air void content should be at least 3%. As shown in the slide, the slope of the AC vs. voids line may vary between mixes.



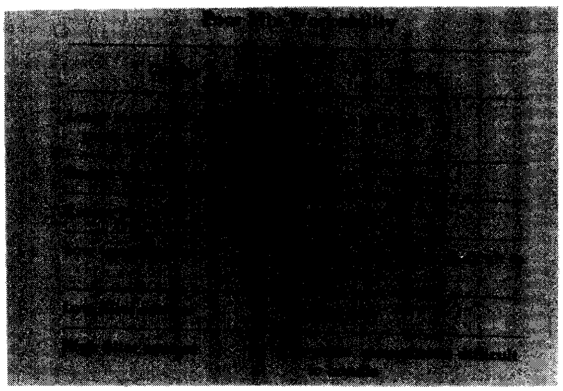
63. The following slides present some common mix deficiences and the cause and effect of them. The first is low stability.



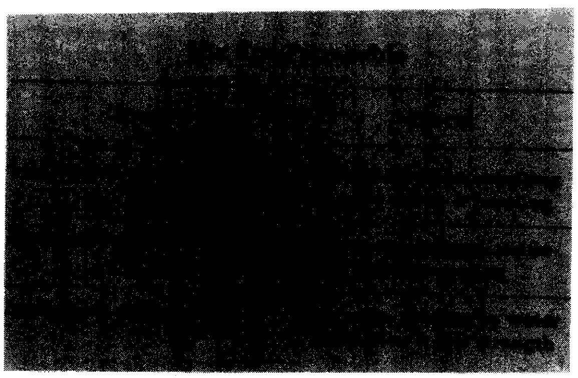
64. Poor Mix Durability



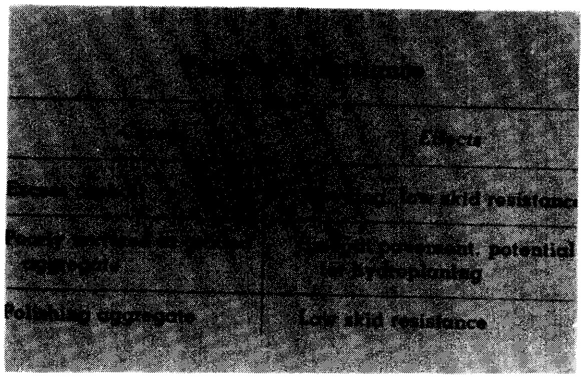
65. Poor Fatigue Resistance



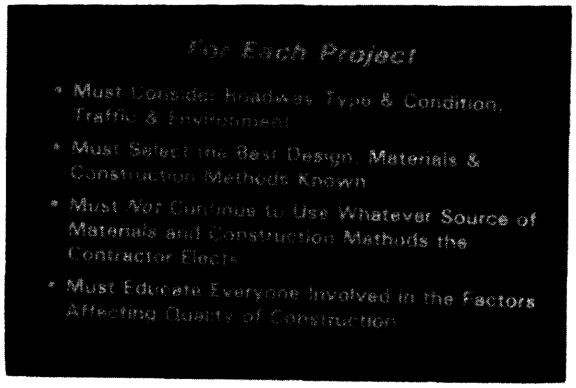
66. Poor Mix Workability



67. Mix Too Permeable



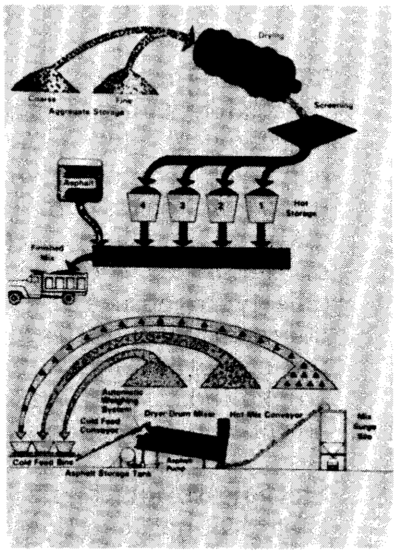
68. Poor Skid Resistance



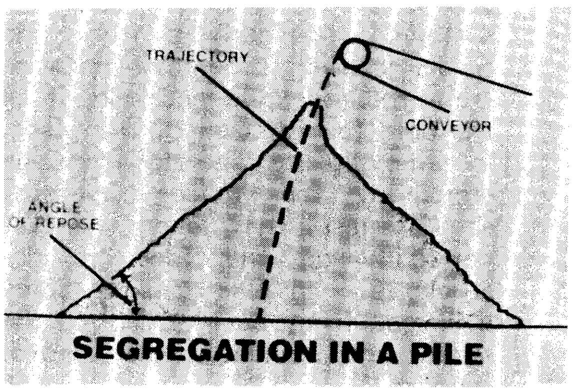
69. In summary, this section has illustrated the necessity of considering the roadway type and traffic in the mix design process. It has illustrated the importance of selecting the proper materials and proportioning them correctly to obtain a suitable mix. The presentation will continue to show the importance of understanding the concepts and principles of each phase in order to assure a satisfactory pavement.

HOT MIX PLANTS

1. Plant Operations: In this section we will discuss the operations of the typical batch plant and the drum mixer plant. This will include a comparison of the batch plant and the drum mixer plant and some of the key factors in producing a high quality mix.

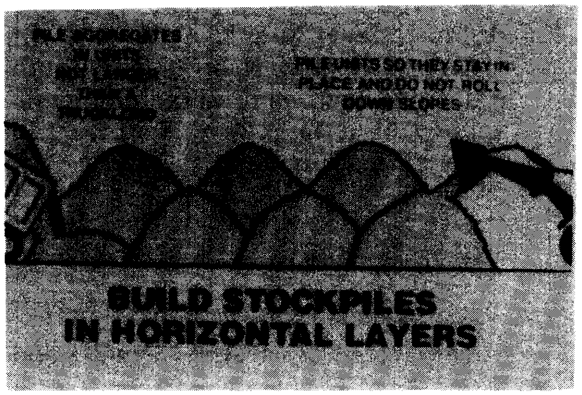


2. Schematics of Batch Plant and Drum Mix Plant operations: The top sketch is a schematic of a typical batch plant. The aggregate travels through the cold feed bins, through the drier, up the hot elevator, over screens and into the hot bins. It is then weighed in the weigh hopper, dropped into the pugmill for mixing, and mixture is deposited into a truck or a storage silo. The bottom sketch represents a typical drum mix plant. The major components are the aggregate stockpiles, the cold feed bins and conveyor, the drying and mixing drum, and a surge or storage silo.

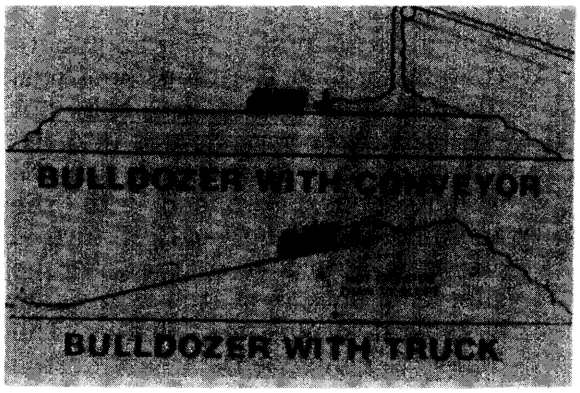


3. Segregated Stockpiles:
Stockpiling is critical to both type plants. Proper stockpiling techniques will ensure that uniform material is being fed into the hot mix plant. The construction of stockpiles in a cone shape or with steep sides can result in severe segregation. As shown in this slide, the large particles have rolled to the outside of the stockpile which will cause segregated material to be fed into

the plant. Although the batch plant with its screening operation is more able to "even out" this segregation, it will result in an nonuniform operation and produce a variable material.



4. Correct Stockpile Construction:
The stockpiles should be constructed in horizontal layers. Trucks or front end loaders can be used to make small piles over the entire area of the proposed stockpile. The tops should be leveled off and a ramp provided for the hauling equipment to start a second layer, and so forth on up.

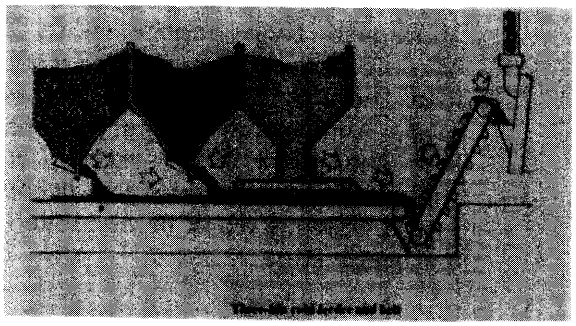


5. Stockpile Layers:
This slide shows a stockpile being constructed in layers with a conveyor system or with trucks by using a dozer to spread the material in layers. The operation of the dozer should be monitored closely to ensure it is not causing degredation or otherwise damaging the gradation of the material being stockpiled. Also, the dozer should not push material down the slope.

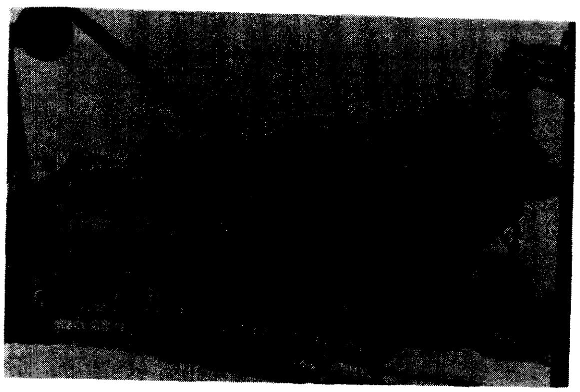
6. The end-result should be stockpiles that are not segregated, that are sufficiently separated, and that are placed on a clean and stable surface. Normally a front end loader is used to remove material from the stockpile and take it to the cold feed system of the plant. In removing the material from the stockpile, the loader operator should pass the loader bucket vertically up the face of the stockpile. In this method some material from each layer in the stockpile is blended in the removal process.

7. Our next subject of discussion in this section will be the batch plant. It's operation will be covered step-by-step with emphases on key items in the control process.

8. Picture of Cold Feed Bins: All plants require cold feed bins where the initial proportioning of the aggregate takes place. The bins should have dividers to preclude any spillover into the adjacent bins.

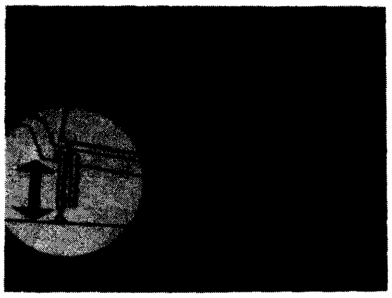


9. Each plant is equipped with an aggregate cold feed system. The quantity of material leaving each bin is regulated by the size of the gate opening, the speed of the belt, or a combination of the two.

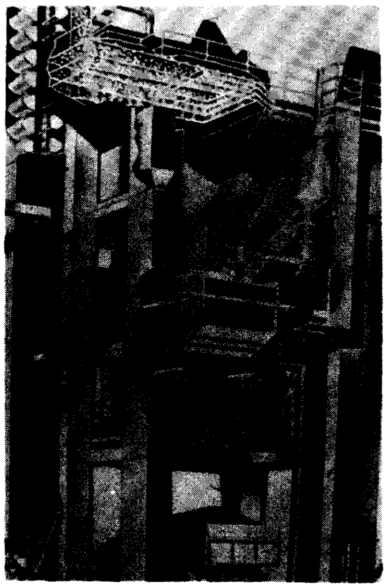


10. In a batch plant the cold feed combined aggregate enters the dryer as shown in this cutaway drawing. Aggregates enter at the upper end, where, as the drum revolves, they are picked up by lifters, called flights. These flights act as scoops, lifting the aggregate particles and dropping them through the flame and hot gases produced by the burner at the lower end of the dryer.

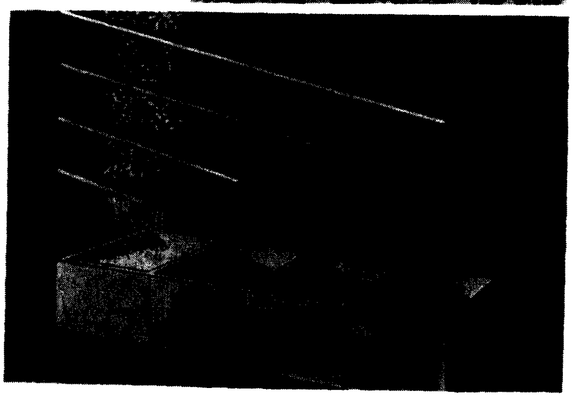
11. The purpose of the dryer is to remove the moisture from the aggregate and to heat it enough to provide the proper mixing temperature in the pugmill.



12. The slope of the drum controls the length of time for drying and heating the aggregate.

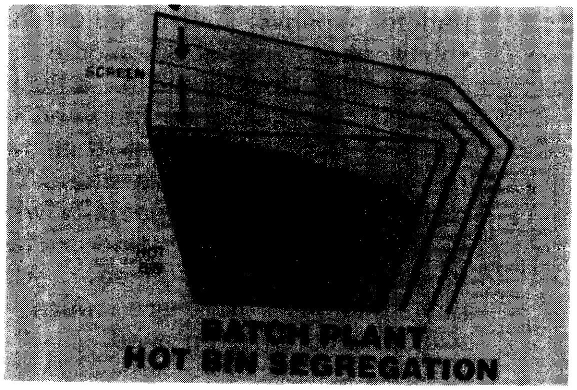


13. Batch Plant Cutaway: The aggregate then continues to the hot elevator, through the screens into the hot bins. It is released into the weigh hopper, dropped into the pugmill for mixing with asphalt, and the mixture dropped into a waiting truck or conveyed to a storage silo.



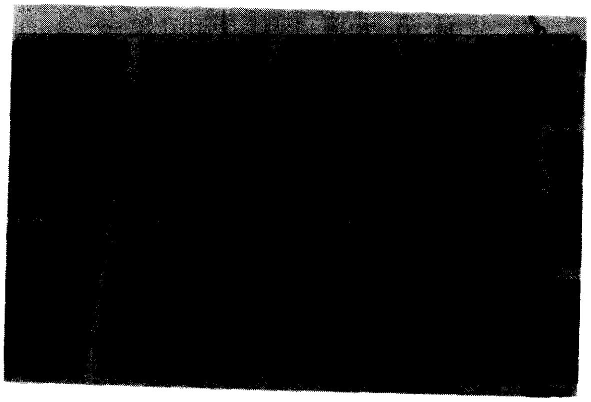
14. The screens provide for the final separation of the aggregate. The degree of control depends on the number of bins used and the efficiency of the screening system. The screens should be of the appropriate sizes and the cold feeds properly adjusted so as to distribute the proper amount of material in the bins. Some specifications require that each bin contain 15% to 50% of the mix design aggregate.

15. The screens should not be overloaded. Overloading the screens, especially in surges, will cause an inconsistent carryover. Carryover is finer material being carried over and deposited into the next aggregate size bin. A review of the hot bin gradation results will indicate how much carryover is occurring. The screens should vibrate properly so that the aggregate is bounced off the screen. The screens should not be blinded by aggregate particles stuck in the openings.

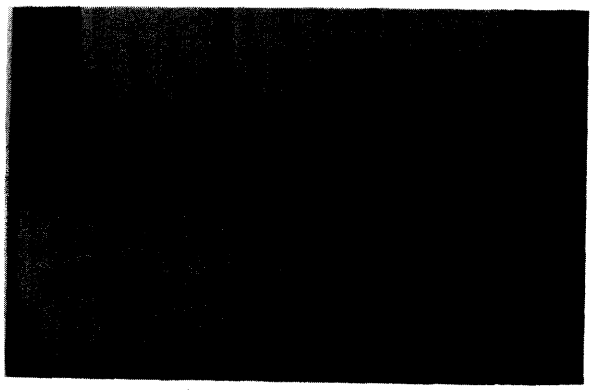


16. The screens should not be torn or have holes in them.

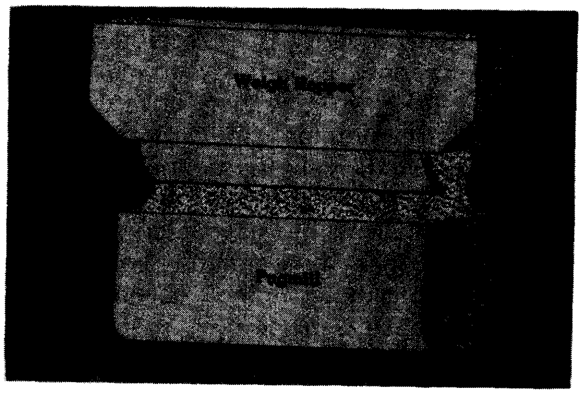
Segregation within a bin as shown is common and sampling techniques must account for that by sampling the entire width of the discharge of the bin.



17. Each one of the hot bins contains an overflow pipe as shown on this slide. This is to prevent any spillover into an adjacent bin caused by overfilling.



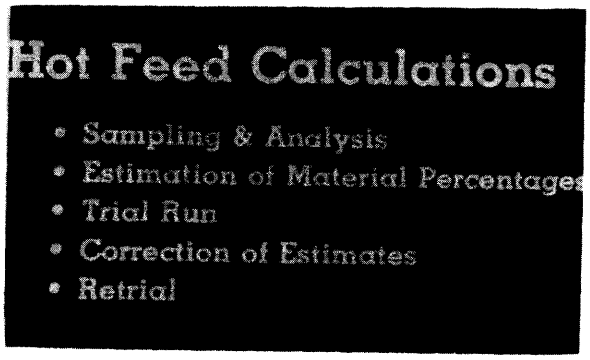
18. The aggregate is then deposited in the weigh hopper one bin at a time. The coarse aggregate is placed on the bottom so that when the materials are dropped into the pugmill the fine material will not be trapped out of the paddle's reach.



19. The aggregates are then dropped into the pugmill. After a short dry mixing, the asphalt is added and mixed. The action of the pugmill paddles and the aggregate shears the asphalt into a very thin film and forcibly coats the aggregate.

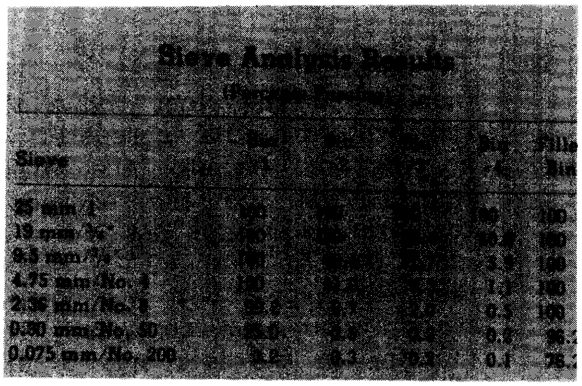
20. Inside the Pugmill: The pugmill is a twin shaft mixer. The two horizontal shafts have several paddle shanks with adjustable, fairly easily replaced paddle tips The paddle tips should be adjusted so that the clearance between the tip and the liner is less than half the maximim aggregate size. This should be checked, especially when a friction course or fine surface course is being produced. Also, any paddles that are worn or broken should be replaced.

21. At maximum operating efficiency the paddle tips should be barely visible at the surface of the material during mixing. If the level of material is too high, the uppermost material tends to float above the paddles. Also, if the level is too low the tips of the paddles rake through the material without actually mixing it. Either of these problems can be avoided by following the manufacturer's pugmill batch rating recommendations.

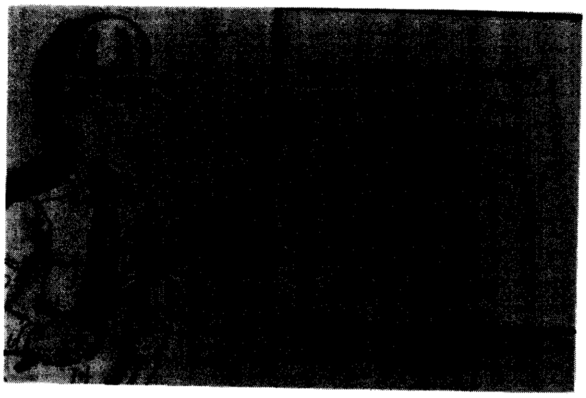


22. The plant should be set up and controlled to give us the mixture we designed in the laboratory. The main factor in setting up a batch plant is determining the weight of aggregate to be drawn from each hot bin. The slide shows the typical steps involved.

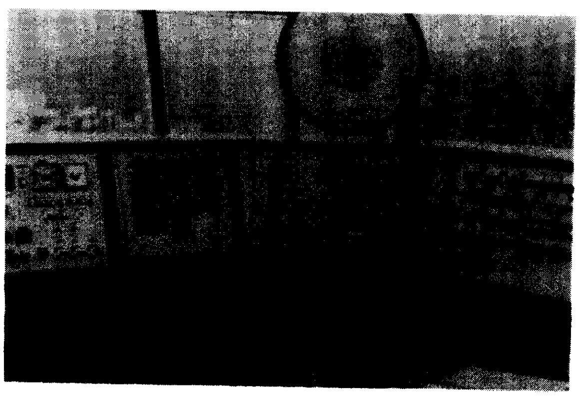
23. Samples are taken from each hot bin. In taking these samples it is important to sample the full width of the bin opening because of the segregation within the bin.



24. A sieve analysis is conducted and the gradation for each bin is determined.

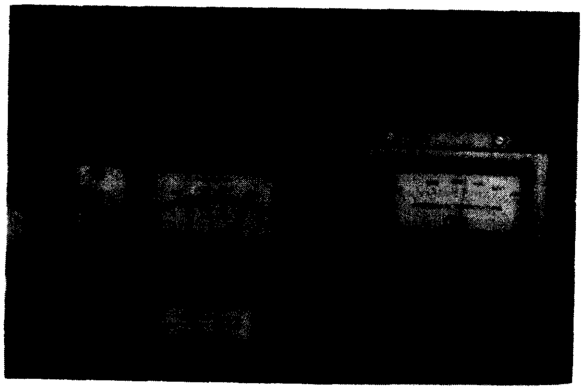


25. From the gradation information, the weight of aggregate that must be drawn from each bin to produce the design gradation can be calculated. Using these estimated weights for each bin, a trial run should be performed and the weights adjusted until the desired mix is produced.



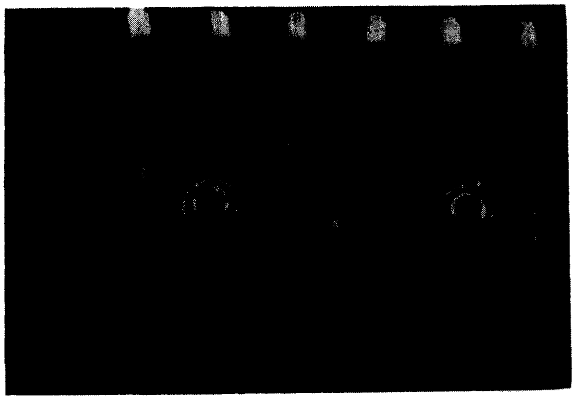
26. The control van or trailer houses the equipment needed to control the mechanical functions of the plant. The aggregate scales are shown here with pointers set at the proper aggregate weights for the design mixture.

27. Hot Bin Control Panel: The control panel of most batch plants contain indicators of the amount of material stored in each hot bin. A constant indication of high or low level is generally caused by improper cold feed proportioning.



28. Temperature Monitors: The monitor on the right shows the temperature of the aggregate. As a rule of thumb, the stack temperature and the aggregate temperature should not vary by more than 25°F to 40°F. If the plant is equipped with a baghouse, it will also have controls. The monitor on the left side of the slide is the baghouse control. The black needle indicates the temperature in the baghouse. The red needle is set around 400°F to control the maximum temperature of the baghouse.

29. Temperature Recorder: The batch plant control room should have a chart recording the temperature of the aggregate leaving the dryer and/or the temperature of the asphalt. If the specifications require that these charts be kept as a part of the records, the time of the day should be properly set.



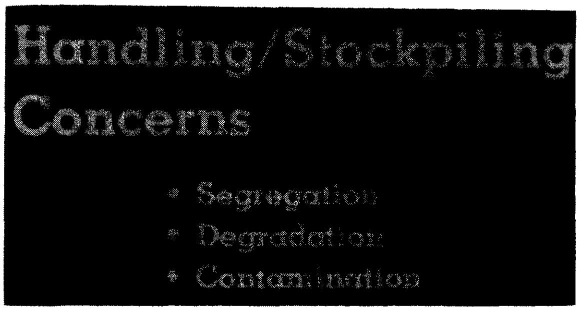
30. Mixing Times: The mixing cycle is controlled by a timer. It will control the wet mixing cycle and dry mixing cycle. The dry mixing cycle, if required, should be only a few seconds. It can be harmful in creating too much fines. It can be benefical if you are working with a coated aggregate by helping to remove the coating.

The wet mix time must be long enough to produce a uniformily coated homogeneous mixture. But because most of the aging of the asphalt occurs in the pugmill mixing cycle, the mixing cycle should be no longer than necessary.

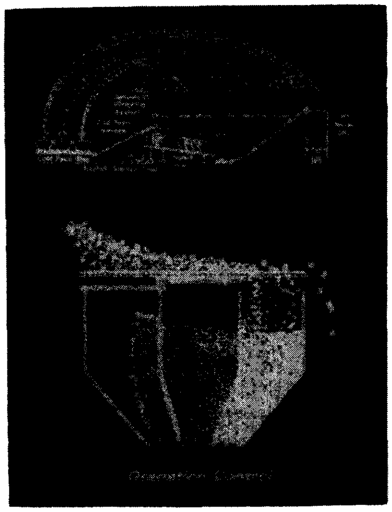
The Ross Count or AASHTO T 195, "Determining Degree of Particle Coating of Bituminous -Aggregate Mixture," can be used to set the mixing time. This system bases the degree of mixing on the percentage of coarse particles that are completely coated with asphalt and correlates it with mixing time.

31. The drum mixer is a relatively simple process for producing hot mix. The key difference between the drum mix plant and a batch plant is that the drum mix plant not only dries and heats the aggregate, but also coats the aggregate with asphalt within the drum.

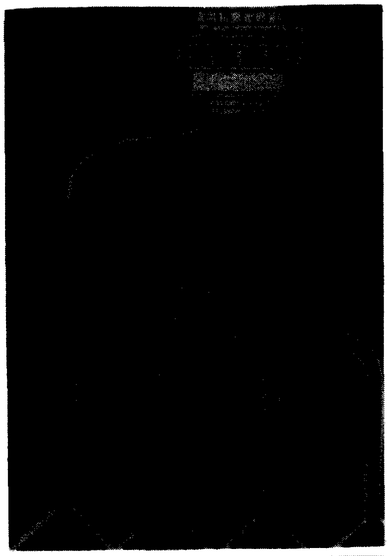
As shown in this schematic, the major components of a drum mixer plant are: the aggregate stockpiles and cold feed bins, the conveyor and aggregate weighing system, the drum mixer, the dust collection system, the hot mix conveyor, the surge bin or silo, the asphalt storage tank, and not shown the control van.



32. The aggregate stockpiles are probably the most important component of a successful drum mixer process. The stockpiling concerns discussed earlier are much more important in the drum mix plant operation than in the batch plant operation, as will be shown.

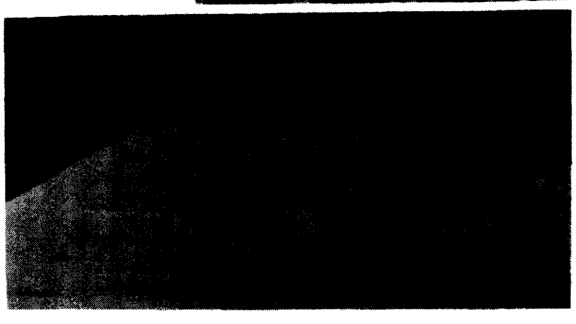


33. Schematic of Screens and Hot Bins: Unlike the batch plant, the drum mixer plants does not have the screens, hot bins, and a weigh hopper. Therefore, the aggregate must be sized and proportioned prior to its entry into the drum. Generally, to provide the same level of mix control, the number of stockpiles in a drum mix operation and the number of hot bins in a batch mix operation must be equal.



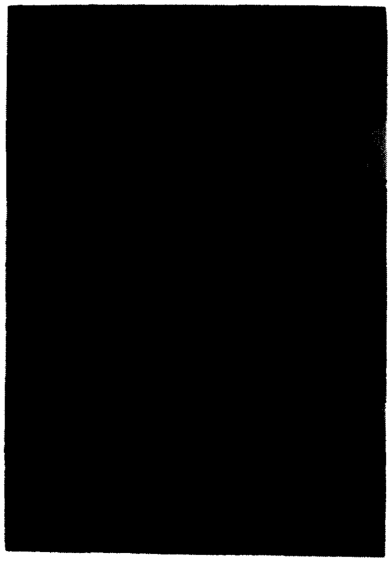
34. This may require a change in the typical crushing and screening operations to provide the necessary number of stockpiles as required and the required particle sizes. The stockpiles must be properly graded and split into at least as many different sized fractions as required. Normally 4 stockpiles for a binder course or minus 3/4" or larger surface course; 3 stockpiles for a minus ½" surface course; and 2 stockpiles for a friction course.

35. Once sized, the aggregate must be properly stockpiled and handled to avoid segregation. Segregated stockpiles cannot be used successfully.



Also, it is important that the minimum size stockpiles, such as a 5 day production quantity be maintained. This is needed for adequate testing and aging of the freshly crushed aggregate.

36. Cold Feed Bins: There must be an accurate multiple cold bin system to properly proportion the material. One major problem in the cold bin operation is spillover into another bin. This can be eliminated by extending the dividers on each bin wall above the top of the sides.

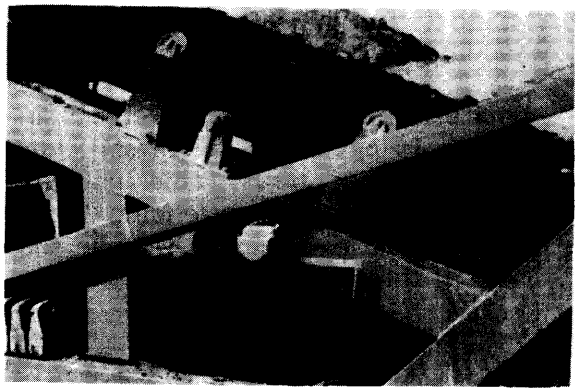


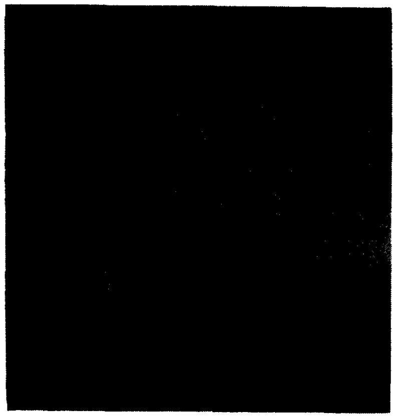
37. Cold Feed Bin Calibration: Each bin must be calibrated separately. The calibration consists of collecting and weighing a timed aggregate sample for several different speeds of the bin belt. The calibration chart is a plot of tons/hours vs. amperage, or frequency, which ever controls the belt speed. The bins must be calibrated each time a different material or aggregate size is used.

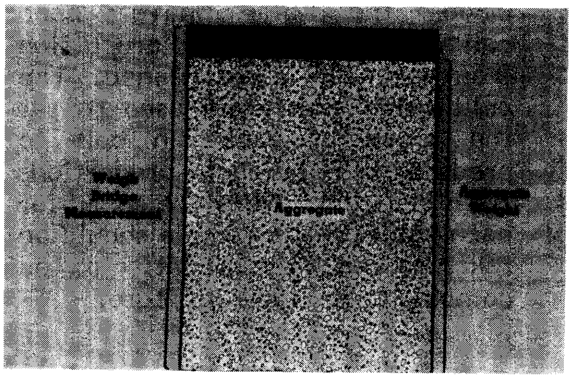
Once the bins have been calibrated, the required proportion from each bin is determined. The calibration charts are used to set the speed of each bin belt to produce the correct proportions from each bin. After the speed for each belt is set, a sample should be taken to check the gradation of the combined aggregate mixture.

The individual bin controls are interlocked to the master cold feed control. Thus the total tonage of aggregate going into the drum mixer can be increased or decreased without changing the proportions coming from each bin.

Each cold feed bin should be equipped with a device to monitor the flow of material from the bin and shut down the operation if the cold feed flow is interrupted.



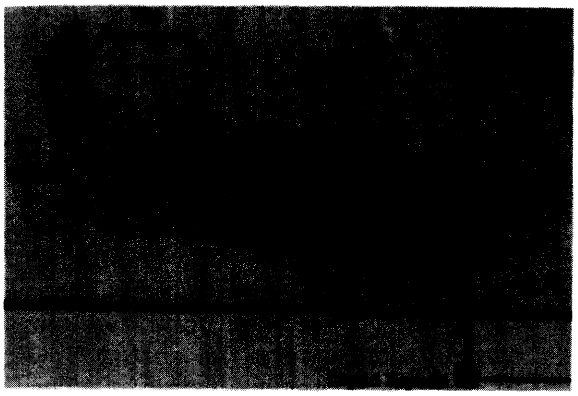




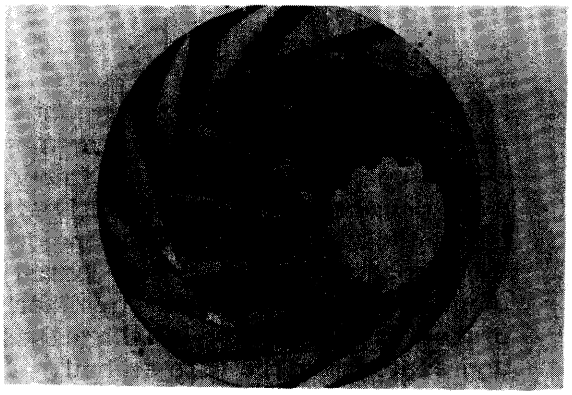
38. Aggregate Weigh Bridge: The drum mixer plant requires a continuous weighing system on the cold feed conveyor belt. One of the conveyor idlers is mounted on the pivoted scale carriage and is designated the weigh idler or weigh bridge. As the material passes over this idler, the weight is translated into TONS PER HOUR and visually displayed at the control center.

39. This reading is necessary for the aggregate/asphalt blending system. During the calibration of the cold feed bins, the accuracy of the weigh bridge should be checked. This should be done by hanging a series of weights on the idler for static calibration and then also actually weighing the aggregate that comes off the belt in a given period of time.

40. It should be remembered that the weigh bridge weighs all the material passing over it. This usually includes aggregate and moisture. Since the total weight determines the quantity of asphalt added, the moisture content of the aggregate must be determined and a correction made. A variation in the moisture content during the operation can have a significant effect on the asphalt content of the mix.

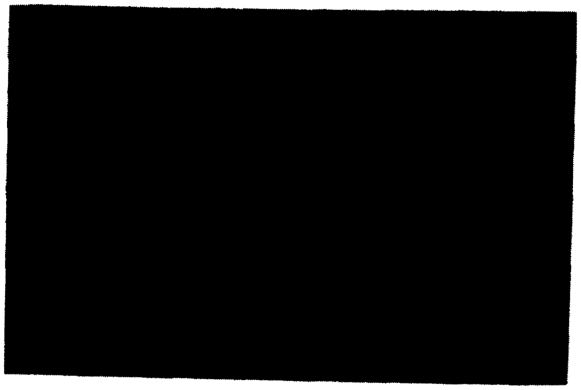


41. Drum Mixer Cutaway:
In the drum mixer the aggregate is charged into the drum at the burner end so the hot gases and aggregate move through the drum in the same direction. The asphalt which is introduced about the midpoint of the drum has to be protected from the harmful effects of oxidation and direct contact with the burner flame. This is accomplished by using the evaporating moisture and the veil of aggregate. Some drum mixer plants utilize a heat shield to protect the asphalt.

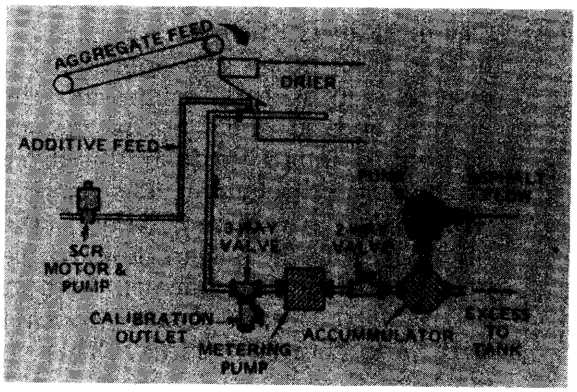


42. FLIGHT DESIGN: Different flight designs are used in the drum mixer to accommodate an environment where both aggregate and asphalt are present. To achieve a uniform drum loading, spiral flights are used at the charging end to convey the aggregate away from the inlet. Tapered lifting flights at the beginning of the drum elevate and discharge the aggregate in a controlled manner to form a uniform veil without smothering the burner flame. Flights throughout the remainder of the drum provide a uniform veil across the drum to protect the asphalt from the burner flame.

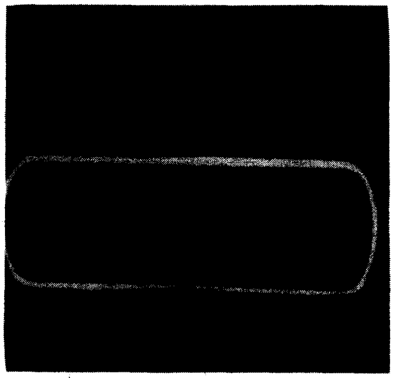
A spray pipe is used to introduce the asphalt into the drum. The point at which the asphalt is injected varies, but is usually in the middle 1/3 of the drum length.



43. Aggregate Veil: In most drum mixers the flights pick up the aggregate and showers it across the full width of the drum. This veil protects the asphalt from the burner flame. Therefore, it is very critical that the aggregate shower produce a uniform veil. Over showering or under showering will result in an overheated or burned asphalt.The addition, deletion or replacement of flights may be required to correct this.

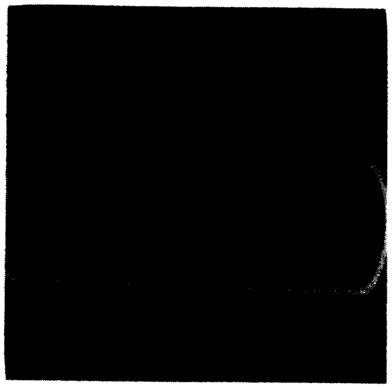


44. Another vital component of the drum mixer plant is an asphalt system capable of providing accurate continuous proportioning of asphalt. Drum mix plants are equipped with an asphalt metering system such as a positive displacement pump or flow meter and adjustment. This metering system should be calibrated using a measured container and weight scales to determine the actual flow of asphalt at various settings. The system should be recalibrated if there is a change in the asphalt supply, temperature, or specific gravity of the asphalt.

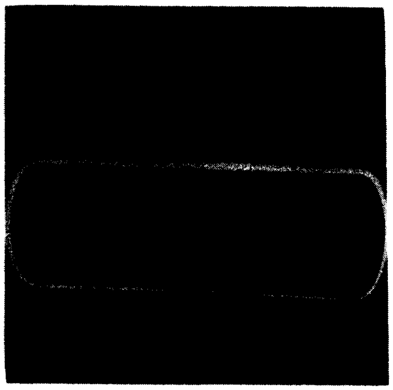


45. Mixing Process: During the smooth continous flow of material, certain events occur in phases within fairly well delineated zones of activity inside the drum. One of the major differences between the batch plant process and the drum mixer process is the manner in which the aggregate is coated with asphalt.

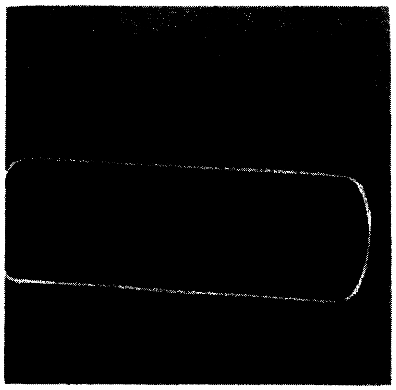
Phase I is the early heating phase. The aggregate has entered the drum mixer, and the surface and free moisture begins to leave the aggregate as the temperature rises.



46. Phase II: In this phase most of the heat rise occurs and the aggregate temperature reaches approximately $170^{\circ}F$ to $180^{\circ}F$. During this phase the majority of the moisture is driven off and the rate of increase in the aggregate temperature levels off.

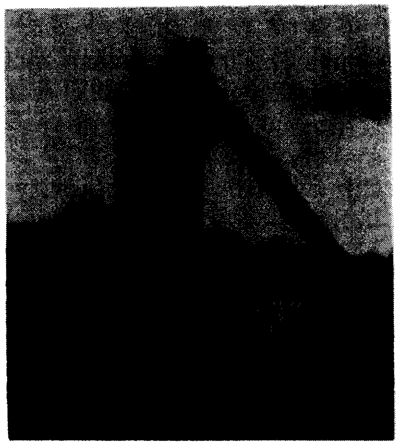


47. Phase III: As the aggregate temperature reaches between $180^{\circ}F$ and $200^{\circ}F$ the asphalt is introduced through the spray pipe. The free and surface moisture driven off now causes the asphalt to foam slightly. This foaming action occurs rapidly and causes the volume of the asphalt to be greatly increased. This action entraps dust as well as the larger particles, and rapidly coats the aggregate.

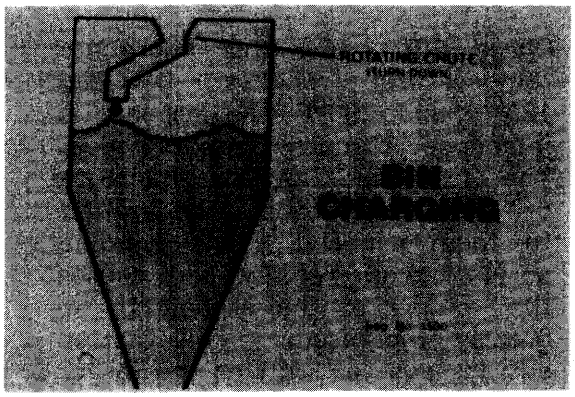


48. Phase IV: In this phase, the final temperature of the mixture is achieved.

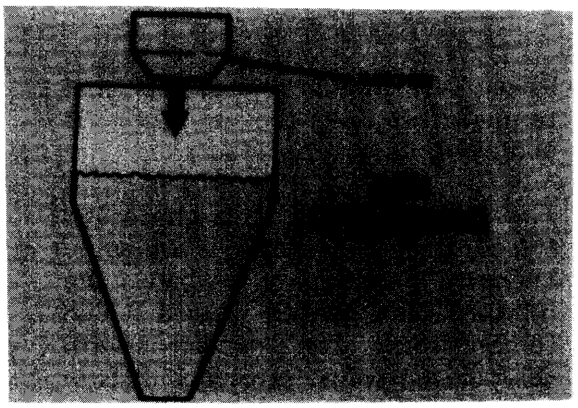
The final portion of this phase and the silo storage phase is of some concern, especially when the mixture is heated to a high temperature. The concern is with the possibility of internal moisture being driven from the aggregate after it is coated. If internal moisture is driven out of the aggregate during this time, it may impair the asphalt/aggregate coating.



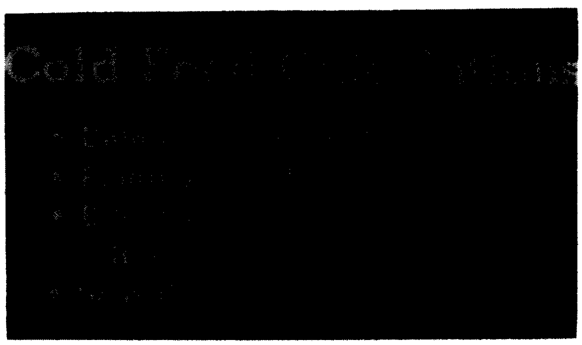
49. Storage Silo: Since the drum ....xer plant is designed to operate in a smooth continuous operation, it is necessary to transfer the mix to a surge or storage silo. This silo may be a source of segregation.



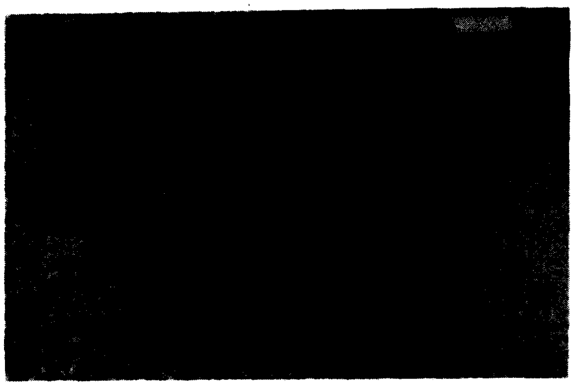
50. The method of charging the silo has been shown to be critical in minimizing segregation. One of the methods proven to cause less segregation is the rotating turned-down shute.



51. Another method which has been proven acceptable is the batcher. When a top batcher is used, it is important that the material drops to the center of the silo and that the batcher fills each time before release into the silo.



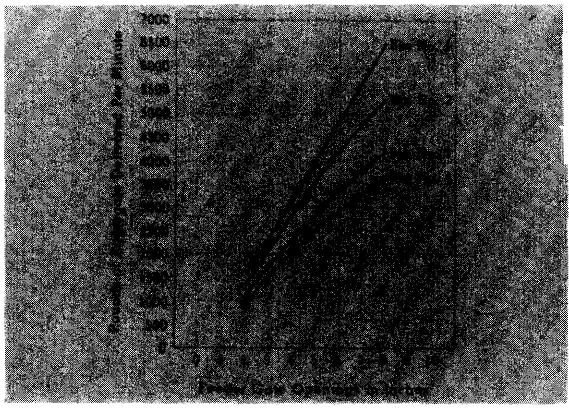
52. Two major factors in obtaining a quality uniform mixture from a drum mix plant is calibration and control of the cold feeds. This slide depicts several of the steps involved in the cold feed calculations.



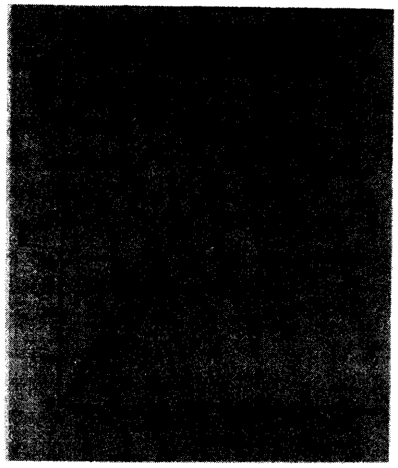
53. The point of sampling of aggregate in the drum-mix operation is at the stockpile. Obtaining a representative sample from an aggregate stockpile is difficult at best. Samples should be taken from several locations over the stockpile and combined and then split if necessary. Aggregate sampling also can sometimes be done off the individual cold feed belts.

54. Each aggregate sample is then sieved to determine the gradation of the material coming from each cold feed bin.

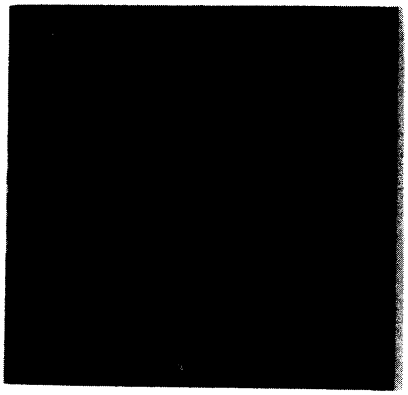
55. Based on the job-mix formula, the percentage of material needed from each cold feed bin is calculated.



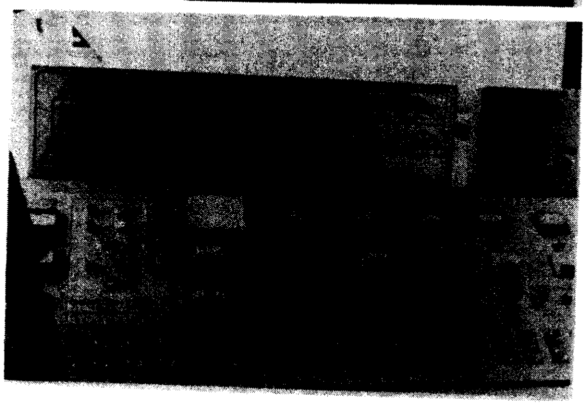
56. In order to set and control the supply of material from each cold feed bin, the bin opening and belt speed must be calibrated. The feeder gate openings for each bin should be varied and the material flow determined for each setting as shown, with the feed belts running at a fixed median speed. The gate openings should then be adjusted to the opening size that will supply approximately the weight of material needed from each cold feed bin.



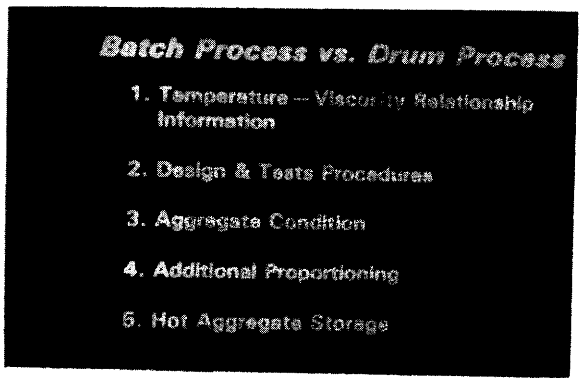
57. The next step in the set-up and calibration procedure is to vary the belt speed and to determine the corresponding rate of material flow. After production begins the slight adjustments necessary will usually be made by varying the speed of the cold feed belts.



58. The asphalt metering and delivery system must be interlocked with the aggregate weighing and delivery system to assure the mix contains the proper asphalt content.



59. The controls for the drum mix plant are generally less elaborate than a batch plant and usually require little action by the plant operator other than monitoring feed rates and temperature.



60. Comparison of Batch vs. Drum Process: To understand the differences in the two processes, the following comparisons are made:

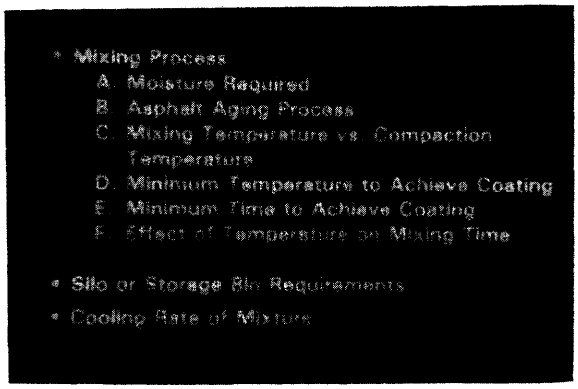
    a. The temperature viscosity relationship is less important in the drum mix as will be discussed in the next slide.

b. Design and Test Procedures - The current test procedures were developed to duplicate the batch plant process. Laboratory design specimens are prepared with clean, hot, dry aggregate and the mixing is by a mechanical shearing action, which is very similar to the batch plant pugmill. The current test procedures do not duplicate the drum process.

c. Aggregate Conditons - The gradation and moisture content of the aggregate in the stockpiles is not nearly as critical in the batch process as it is in the drum process. The dryer, hot elevator, screens, hot bins, proportioning, and dry mixing phases of the batch process help to remove aggregate coating and internal moisture, to produce a clean, hot, dry aggregate for mixing. In the drum process, the gradation, moisture, and aggregate condition have to be controlled at the stockpile.

d. Additional Proportioning - The screening, hot bin storage, and proportioning phases of the batch process are the key elements in controlling the gradation and aggregate-asphalt proportions of the mix. In the drum process, the aggregate gradation is controlled at the stockpiles and the proportioning is controlled at the cold feed bins. The aggregate passing over the weigh bridge must have a constant moisture content and gradation, if the asphalt content is to be constant.

e. Hot Aggregate Storage - The aggregate is stored for a period after heating in the batch plant operation. This allows time for any trapped moisture to escape.

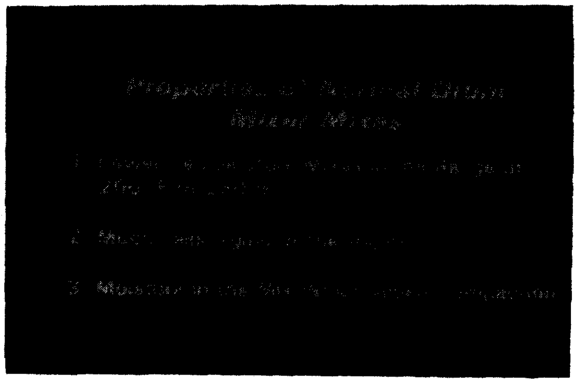


61. Mixing Process - In the batch process, mixing is accomplished by a mechanical shearing action to obtain a very thin coating of asphalt cement on each aggregate particle. The temperature-viscosity relationship information is needed to determine the proper mixing temperature for the asphalt being used. Temperature, asphalt viscosity, and wet mixing time are critical elements in the batch process. The aggregate is hot, dry, clean, and starting to cool when the asphalt is introduced and the mixing process takes place.

In the drum process, the aggregate is coated immediately with foaming asphalt. This is an asphalt coating process rather than a mixing process. The operating temperatures of the plant is not dependent on the temperature viscosity relationship of the asphalt. The operating temperature needs to be high enough to remove all but about 1 percent excess moisture. The 1 percent excess moisture is needed to allow foaming of the asphalt cement. Excess moisture in the aggregate delays foaming of asphalt, and may result in inadequate coating of the aggregate and heating of the mix. Insufficient moisture in the aggregate may result in a lack of foaming, resulting in inadequate coating.

Storage silo - The storage or surge silo, which is required in the drum mix plant, can lead to segregation problems if not properly operated.

Cooling Rate: Because of the moisture in the drum mix, the cooling rate may be faster than a batch mix because of the evaporation. This affects the allowable time to achieve compaction before the mix temperature cools to 175°F.

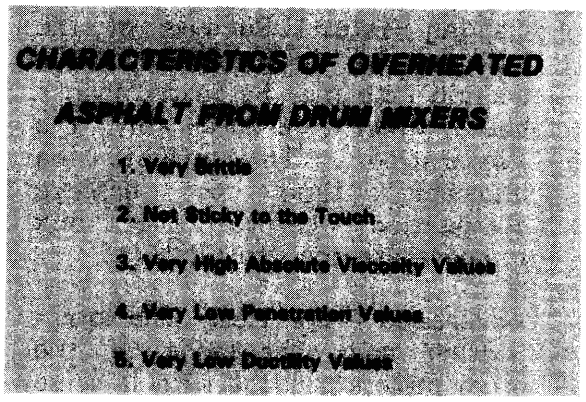


62. Advertised Properties: The introduction and acceptance of the drum mixers brought with it some advertised benefits on the properties of the mixes produced in this type plant. Some of those were:

1. The lower temperature mixes resulted in energy and fuel savings. Typically, mixes were being produced in the range of 200°F to 250°F. This was much less than the 275°F to 325°F temperature range of the conventional batch plant process. These lower temperatures, however, allowed less time between production and compaction.

2. The lack of age hardening of the asphalt in the drum mixer process compared to the batch plant process was very noticable. The asphalts in the discharged mixes were practically as soft as the original asphalts. The reduction in age hardening was so noticable there were discussions of using a harder grade of asphalt.

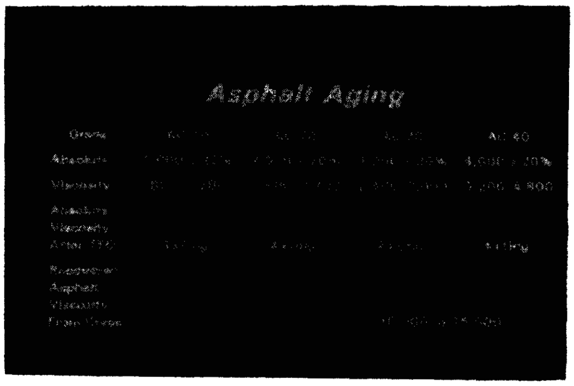
3. The presence of moisture in the mixture was thought to act as a lubricant and aid in the compaction of these lower temperature mixes.



63. However, difficulty in obtaining adequate compaction of these lower temperature mixes became the rule rather than the exception. As a result, the mix temperature was increased, which many times was accomplished by a lowering of the production rate. Today, many drum mixers are discharging mixtures at 275°F to 300°F. Thus, these mix temperatures are the same as those in the batch plant process.

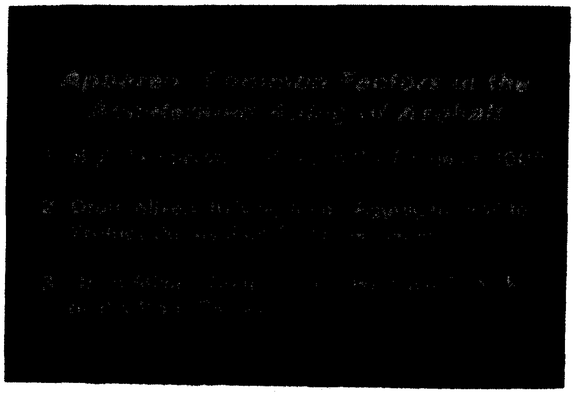
This combination of higher mix temperatures and lower production rate in some drum plants reduced the aggregate veil that protected the asphalt from being overheated. These burned or severely aged asphalts had the following characteristics:

1. Very brittle
2. Not sticky to the touch
3. Very high absolute viscosity values
4. Very low penetration values
5. Very low ductility values



64. Asphalt Aging: We know that two identically graded asphalts from different sources can have quite different aging characteristics. The blending of crude sources can also change the aging characteristics.

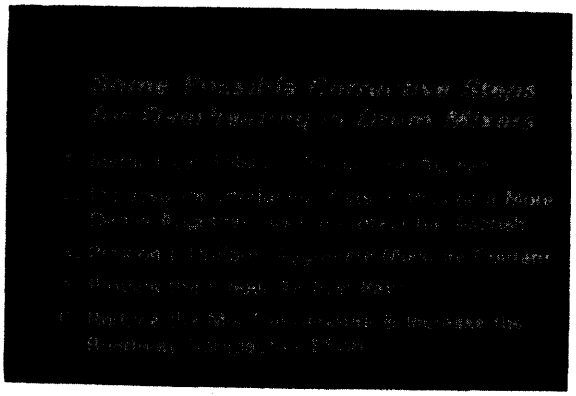
AASHTO specifications limit the absolute viscosity of the asphalt after the TFO or RTFO test to a maximum of four times the original absolute viscosity. Of concern is the recovered asphalt of a mixture being discharged from a plant, and/or of roadway cores from new or relatively new pavements, which has a high absolute viscosity value, very low penetration values and almost no ductility.



65. Common Factors of Aged Asphalt: There appears to be some common factors associated with the accelerated aging problem.

These common factors are:
1. High temperature mixes of approximately 300°F.
2. Mixes produced in a drum mixer which relies solely on an aggregate veil to protect the asphalt from the burner flame.
3. When the drum mixer is operated at less than about 70% of its capacity.

It does not appear that the problem occurs in lower temperature mixes when the drum mixer is operating in excess of about 70% of its capacity, or when the drum mixer is equipped with a heat shield or similar method to protect the asphalt from the burner flame.



66. Possible Corrections: Where overheating or accelerated aging of the asphalt occurs, several corrective actions can be taken as shown on the slide.

67. Water in the Mix: A mixture produced in a drum mixer process will probably contain some moisture. In 1972 and 1973 the North Dakota Highway Department allowed the use of drum mixers on several projects while closely monitoring and recording the mixture properties. One of the items recorded was the moisture contained in the mixture during various phases of the operation. This chart shows the results of their findings.

If a moisture correction is not made in an extraction sample, or the sample is not dried, the moisture will show up as asphalt in the test results. Also, when running an extraction test on a drum mixer mixture, or any mixture where the baghouse fines are used, an ash correction should be determined for each plant and each mix type/aggregate combination. If the ash content increases and a proper correction is not made, the excess ash may be paid for as asphalt.

Further, if the Rice Method, AASHTO T 209, is used to determine the Maximum Theoretical Specific Gravity of a loose mixture produced in a drum mixer, the results may need to be adjusted because of the moisture.

68. Temperature Drop: Finally, the evaporation of the moisture will increase the rate of cooling of the mixture. Therefore, especially in cool weather, the combined hauling, laydown, and compaction time may become very critical to obtaining satisfactory roadway densities.

Test results and field experience indicate that lower temperature mixes do require more compactive effort to obtain densities equal to mixes of more conventional temperatures.

69. Batch Plant/Drum Mixer Sketch. In summary, it should be remembered that the screens, hot bins and weighing are the key elements responsible for the quality control in the batch plant. But in a drum mix operation the key elements are the stockpiling and cold feed operations. Therefore, to maintain the quality control in a drum mixer process the screening must take place before the aggregate is stockpiled; the stockpiles have to replace the hot bins; and the cold feed operation replaces the proportioning.

Until about 10 years ago, most mixes were produced in batch plants. The batch plants had been used for years and we had experience and knowledge of the batch plant process. However, many of the contractors have since switched to the drum process. The drum process produces mixes which usually have properties and characteristics different from mixes produced in a batch plant. But if properly set-up and controlled, either process can produce a satisfactory high quality uniform bituminous mixture.

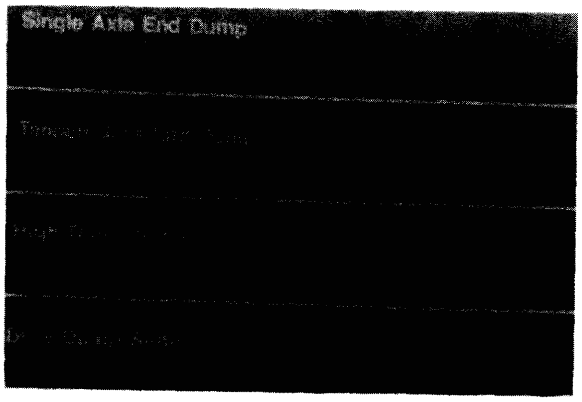
PLACING HOT MIX

1. Placing Asphalt Hot Mix
Up until this point we have concentrated our efforts in selecting and testing the materials and designing and manufacturing the hot mix. However, if the placement of the mix is not done properly all of the preceding efforts and cost are largely wasted.

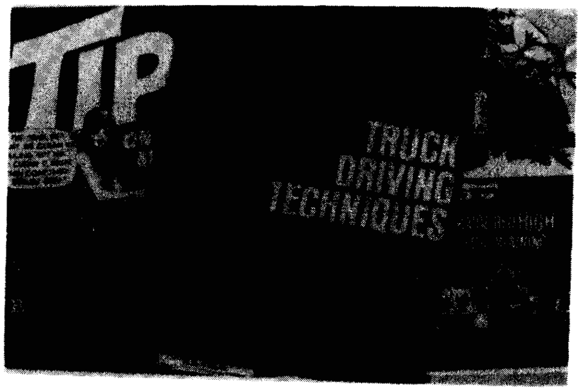
2. Whether we are placing hot-mix on a subgrade or as an overlay, proper preparation of the surface is essential. If we are going to construct a strong durable asphalt pavement, it must be placed on a well prepared firm foundation. All weak and yielding spots should be removed or replaced prior to placing the asphalt mat. Just prior to placing the asphalt, the surface should be swept clean of loose and foreign material.

3. Priming or Tacking the Surface
The final step prior to placing the asphalt mat is the application of a prime coat or tack coat. Generally it is recommended that a tack coat be applied prior to placing each pavement course. When constructing successive asphalt courses with little or no delay, a tack coat may not be needed.

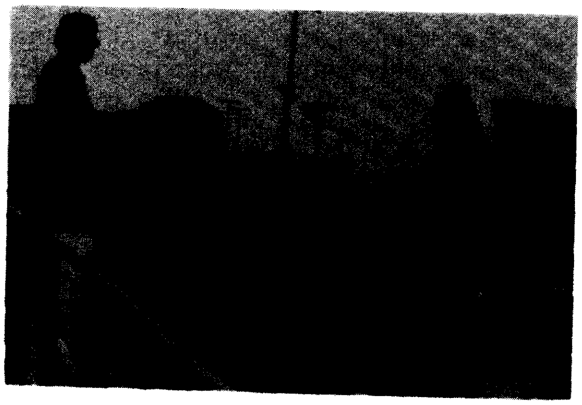
4. When placing the asphalt adjacent to an old pavement layer as shown here it is essential to tack the joint to aid in making the joint watertight.



5. Types of Trucks
There are several types of trucks used to transport the hot mix from the plant to the paving site. Probably the most common is the tandem axle dump truck carrying approximately 15 tons of mix. Using the proper number of trucks is a key factor in providing a steady flow of material to the paver. This is dependent upon the size of the project, and the length of haul.

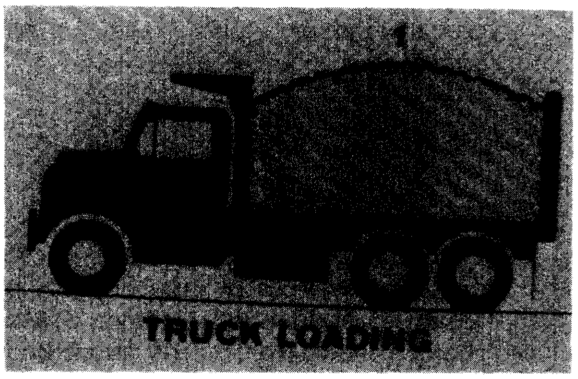


6. Picture of NAPA Truck Driving Techniques
The National Asphalt Pavement Association publishes a booklet called "Truck Driving Techniques." It provides a good review of proper techniques for everyone who is a part of the asphalt paving team.



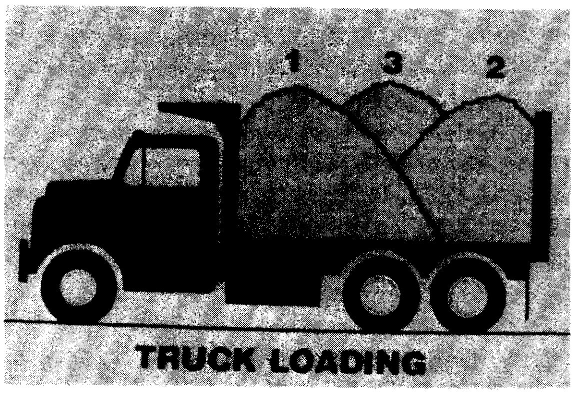
7. A Truck Being Prepared for Loading
Regardless of the type hauling unit used, it is important that the truck be kept in good, safe operating condition. A non-petroleum release agent is recommended for keeping the truck bed clean. The use of diesel should not be allowed as a release agent.

8. The truck bed should be well drained prior to the hot mix loading operations.



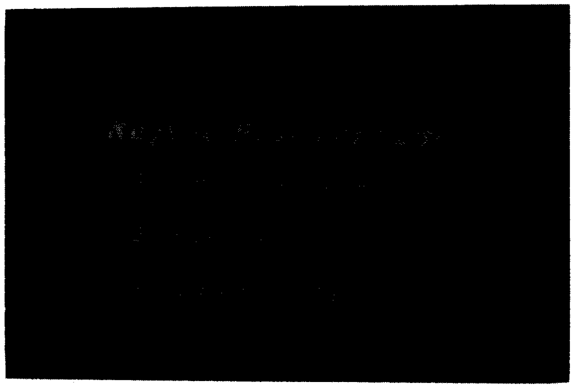
9. Improper Truck Loading
Improper truck loading is a very likely cause of segregation. Due to the rapid truck loading, drivers tend to pull under the bin and load without moving their trucks. As shown in this slide, when a truck is loaded without moving, the coarse material will roll to the front and rear of the truck as well as each side.

As trucks are dumped, the last material from a segregated truck load and the first coarse material on the next truck are combined to increase the amount of segregated material. The coarse material coming from the sides of the truck is usually then deposited in the wing area of the paver hopper and remains there until the hoppers are dumped. If the hoppers are dumped between truck loads, this adds to the volume of segregated material. This operation usually produces a segregated spot at the end of each load and is usually at a very constant interval where the truck loads are of the same size.

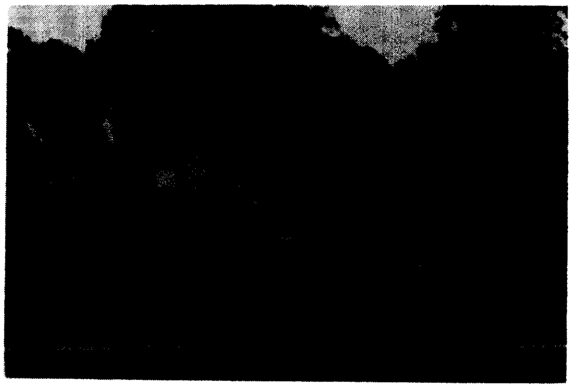


10. Proper Truck Loading Procedures
This slide shows the proper procedures for loading a truck. The first drop should be made at the front of the truck bed near the cab. The second drop should be made near the rear of the truck. The final drop should be made in the center of the truck. This procedure requires the coordination and effort of both the truck driver and the plant operator.

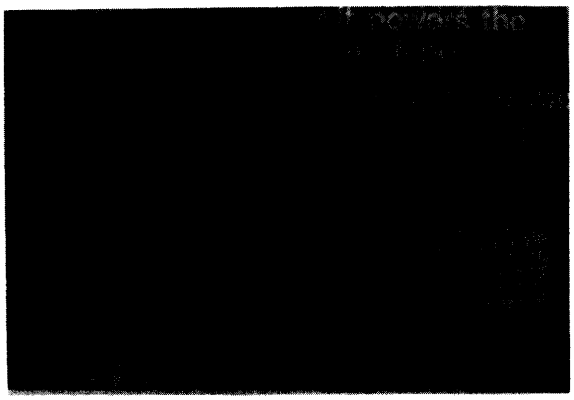
11. Insulation and Tarps
In order to retain the heat during hauling especially in cooler or windy conditions, many States require insulation of the truck beds and a tarp cover.



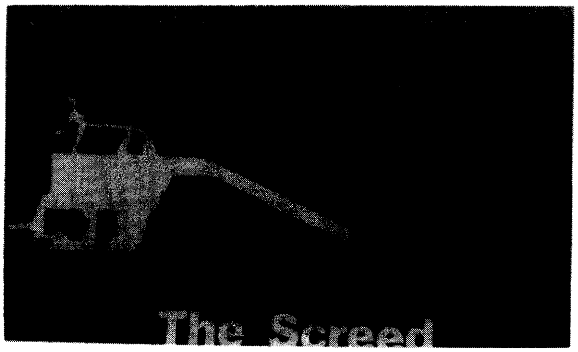
12. Keys to Pavement Life
In order for an asphalt pavement to perform properly, several objectives must be met during the laydown operations. Those key goals are:
    1. A smooth mat surface which eliminates the detrimental effects of dynamic loading from a rough surface.
    2. A uniform mat thickness which will have a uniform rolldown.
    3. A uniform mat density which will result in uniform densification under traffic.



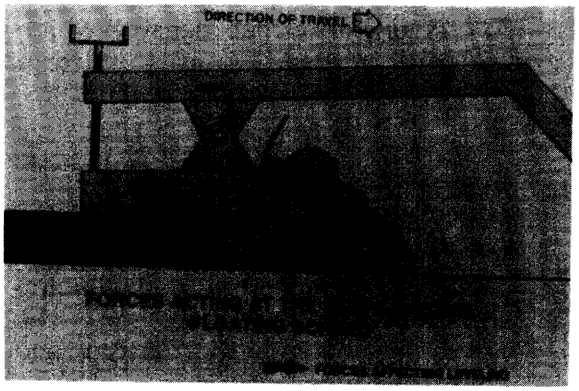
13. Paving Train
If the paving equipment is to do its job it is important that everyone who has a responsibility for placing the hot mix understand the principles behind the design and operating characteristics of the paver.



14. The paver consists of two units, the tractor unit and the screed. The tractor unit supplies all the power needs of the paver. It moves the paver down the road at a uniform speed, receives the mix, and moves the mix to the screed. Screw augers located at the rear of the tractor unit distribute the material laterally so that a controlled amount of material is kept in front of the screed at all times.



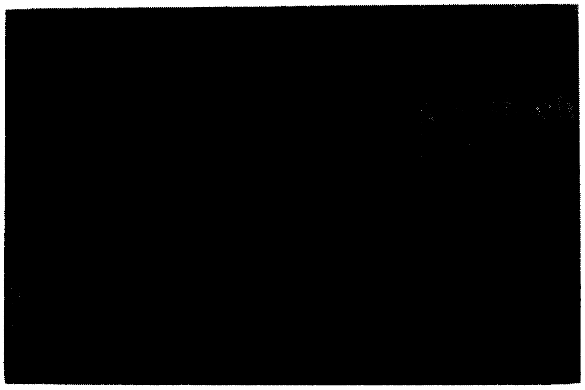
15. The Screed Unit
The screed unit is towed by the tractor unit. It consists of the screed plate, vibrators or tamper bars, thickness controls, crown controls, and screed heaters.



16. Screed Forces
The screed is connected to the tractor unit by a single pin connection on either side. All pavers operate on the same principal as to leveling and control of thickness of the mat. As the screed is pulled into the material, it automatically seeks the level at which all forces acting on it are in balance. This slide illustrates the forces acting on the screed. Basic action of the full floating self-leveling screed may be compared to a water skier who is pulled along the water surface with skies tipped up just enough to support the weight.

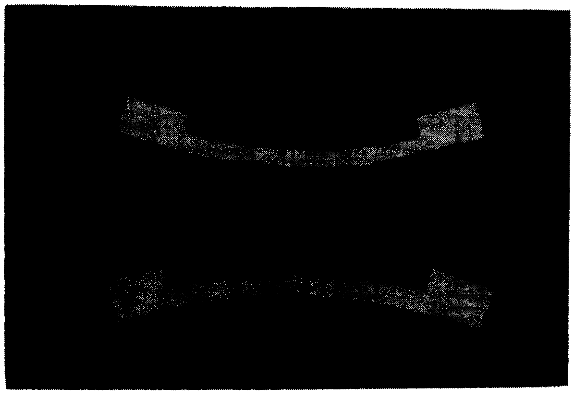
17. Vibrating Screed
In addition to striking off the mix at the proper elevation and maintaining the correct mat thickness, the screed also consolidates the mix and imparts the initial compaction. The amount of initial compaction developed by the screed varies with the properties of the particular mix being placed but is usually about 80% of the target density. All pavers employ one of two methods to consolidate the mix. The vibrating screed, as pictured here, is the method used by most pavers. The vibration of the entire screed consolidates the mix and imparts the initial compaction.

18. Tamper Bar Screed
The other method of consolidation found on some pavers is known as the tamper bar screed. Instead of vibrating the entire screed, the tamper bar slides up and down the leading edge of the screed to compact the mix just enough so that the screed can follow smoothly over the tamped mix. The tamper bar should extend 1/64 of an inch below the screed at the bottom of the stroke.

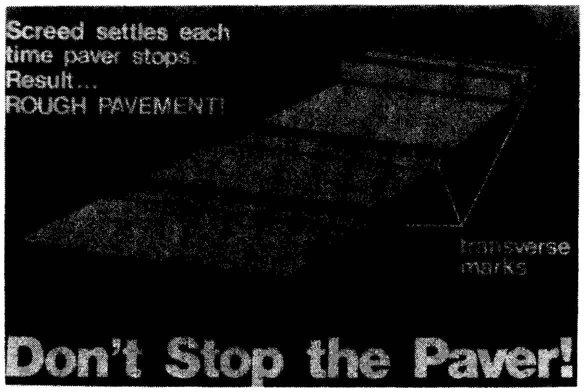


19. Screed Crown
The crown adjustment of the screed is important for proper texture behind the paver. Both the leading and trailing edges can be crowned independently. The leading edge of the screed should have slightly more crown than the trailing edge. As pictured here, too much crown in the leading edge of the screed will produce an open texture in the mat along the edges. Too little crown in the leading edge will cause an open texture down the center.

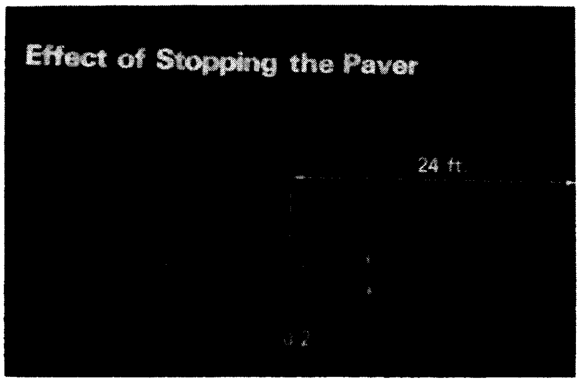
20. Screed Heater
The screed unit is also equipped with a fan-augmented heater. Heating of the screed prevents the mix from sticking to the screed plate. The heaters are only to be used to heat the screed plate at the start of the paving operations. However, the heaters should never be used to attempt to add heat to the mix being delivered to the paver.



21. Screed Too Hot
The bottom of the screed must be smooth and true to place the mix properly. In addition to normal and/or uneven wear the screed can be overheated which may warp the screed by causing it to buckle down or up.

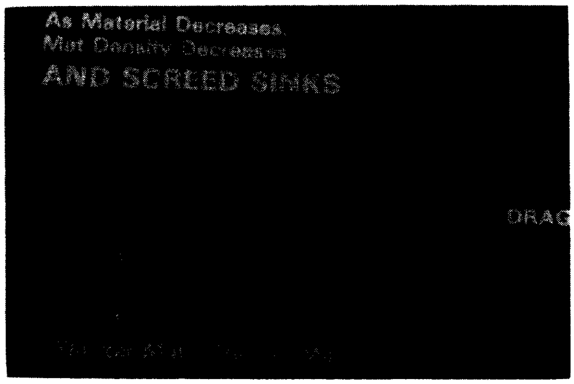


22. Don't Stop the Paver
In addition to the paver being properly adjusted and in good operating condition, there are some basic operating guidelines which must be followed if we are to build good, smooth pavements. The first and probably most important operating rule is to keep the paver moving at a constant speed, and don't stop. At every location where the paver stops, the screed leaves an imprint in the surface of the roadway that can not be rolled out.

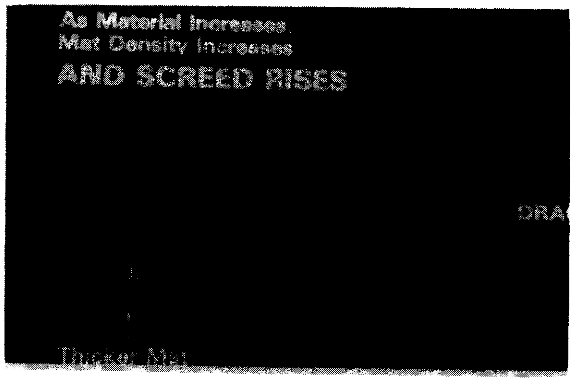


23. Effects of Stopping
When the forward motion is resumed after a prolonged stop, the screed rises up on the cooler material which is in the auger area. This causes a slight thickening of the mat for a short distance and results in a bump in the pavement. It is a simple matter to calculate the paver speed needed to match the plant output or the truck delivery capacity. Therefore there is no reason to start-stop, start-stop.

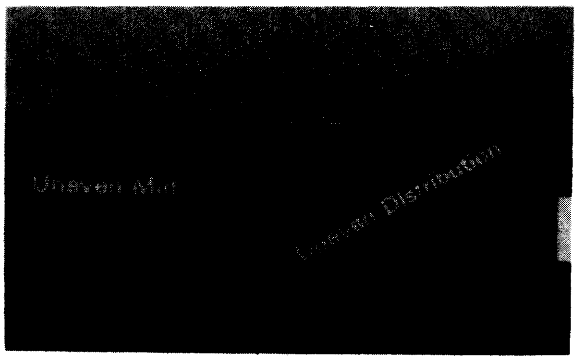
Another common occurrance is the truck backing into the paver. When the truck bumps the paver, the floating screed is knocked into the mat. The truck should always stop in front of the paver and be picked up as the paver moves forward.



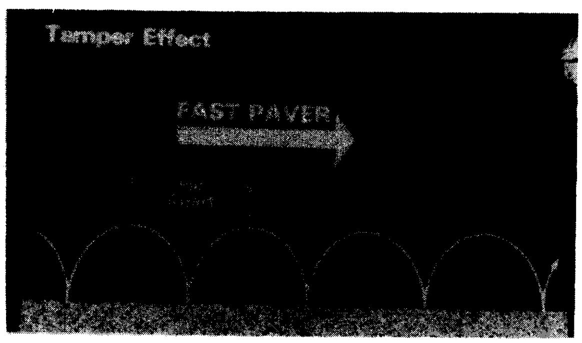
24. Auger Underloaded
The failure to deliver a constant supply of mix to the spreading augers is another poor practice that will cause waves, texture problems, and rough pavements.
Too little mix ahead of the screed will cause the mat density to decrease under the front of the screed. This slight decrease in mat density will slightly reduce the bearing capacity of the mix as the full screed moves unto it. As a result the screed will sink into the mix producing a thin mat.



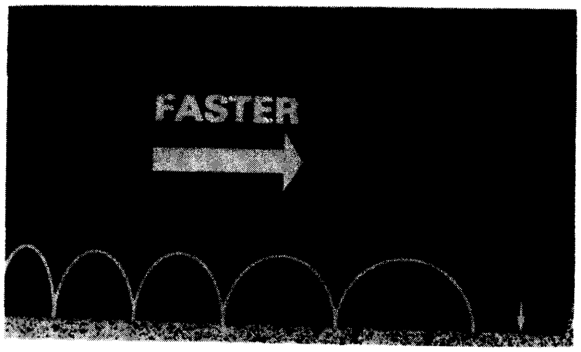
25. Auger Overloaded
Too much mix ahead of the screed will cause an increase in the mat density just under the front of the screed. This will result in a slight increase in the bearing capacity of the mix causing the full screed to rise and produce a thicker mat.



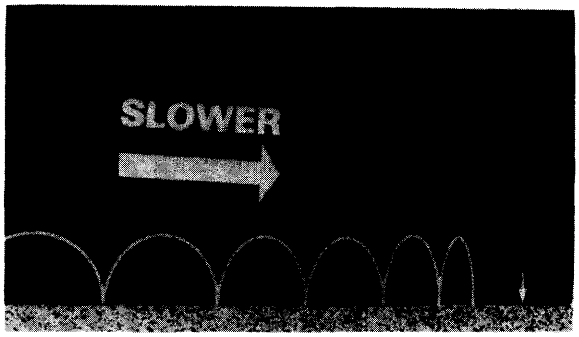
26. Auger Distribution
An uneven distribution of material can likewise effect the density of material under the front of the screed and can produce an uneven mat thickness. Therefore it is important to keep the auger distribution of the material as even as possible. Most properly adjusted paving machines will automatically keep a steady supply of material in front of the screed.



27. Paver Speed
Failure to hold the forward speed of the paver constant is another important factor which can cause variations in the mat smoothness and surface texture. The tamper or vibrator speed is generally fixed and as the paver speed changes the energy imparted to the mat changes. This change in compactive effort will result in changes in the mat thickness.

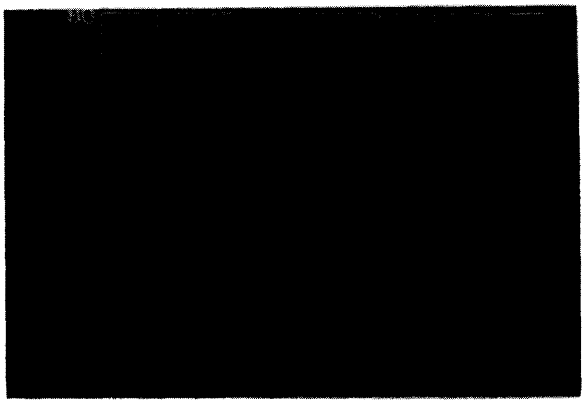


28. Faster Paver Speed
For example, if the paver speed is increased, the tamps or vibrations are spaced farther apart. This imparts less compactive effort to the mat and lowers the density and bearing capacity under the front of the screed. Therefore the mat becomes thinner.

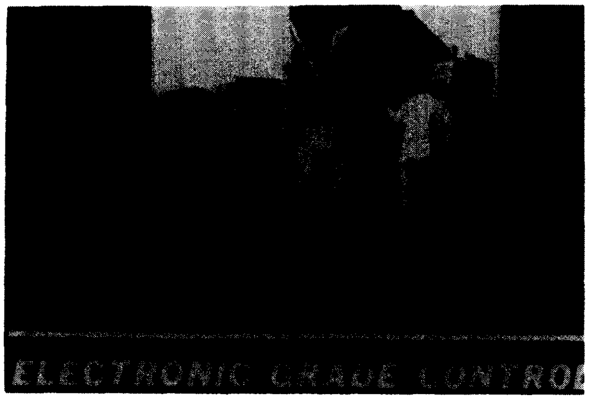


29. In contrast, if the paver is slowed down, more energy is imparted to the mat. This increases the density and bearing capacity of the mix under the front of the screed causing it to rise, increasing the mat thickness.

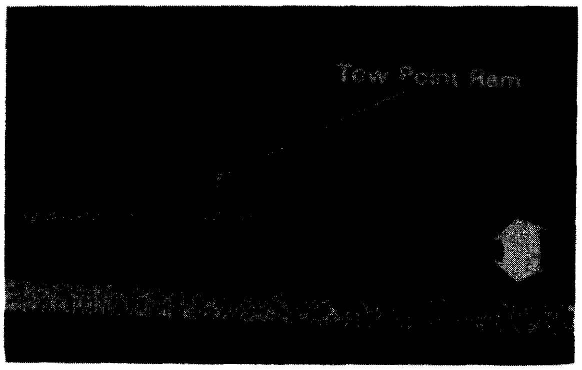
30. Effect of Paver Speed
This slide summarizes the effects of varying the paver speed. It is simply not possible to obtain a mat of uniform density and satisfactory smoothness unless the forward speed of the paver is held constant. On many projects the paver speed is much too fast for the plant capacity or the delivery capacity of the trucks. The speed of the paver could be slowed to match the controlling plant or delivery capacity and eliminiate many unnecessary start-stop operations and variations in the forward speed of the paver.



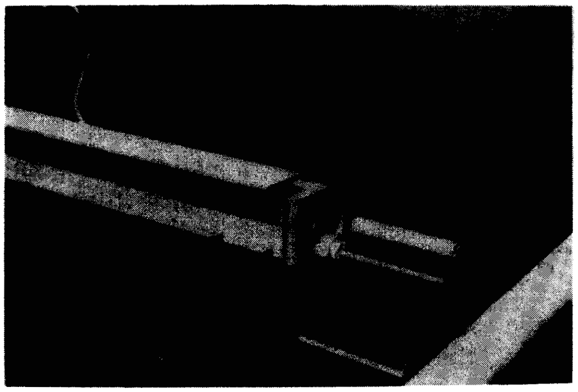
31. Paving Speed Versus Mat Thickness
This slide shows curves from which paver speeds can be determined for various mat thicknesses and various plant production or truck delivery rates in tons per hour. For example, if a hot mix plant producing 250 tons per hour supplying a paver placing a mat 3" thick and 12' wide, the paver speed must be 20' per minute to balance the laydown rate with the production rate at the plant. In some cases the delivery capacity of the trucks is the controlling factor in which the delivery rate should be substituted for the plant production rate. Similiar curves are available in publications by The Asphalt Institute and other such agencies.



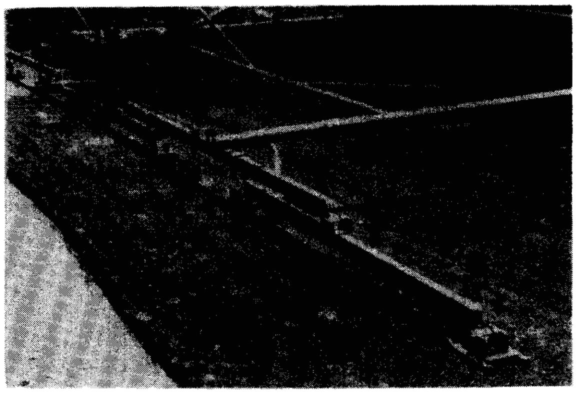
32. Grade Control
Most States specify that electronic grade controlled pavers be used. This equipment makes it possible to keep all layers more uniform in thickness thus providing a smoother pavement.



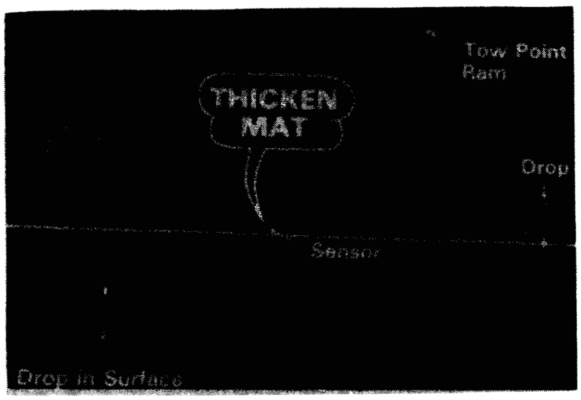
33. Tow Point RAM
By means of the grade control system, the angle of attack of the screed can be varied.



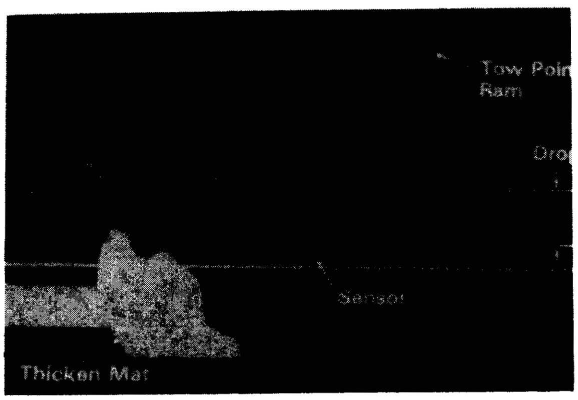
34. Stringline Grade Control
The grade is controlled by a sensor which takes signals from a stringline or wire.



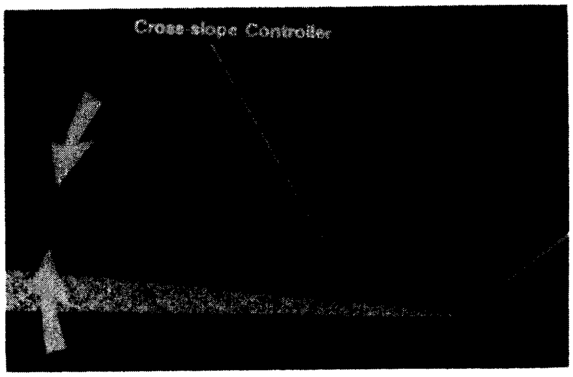
35. Ski Control
The wire is usually mounted on an adjustable length ski as shown in this slide.



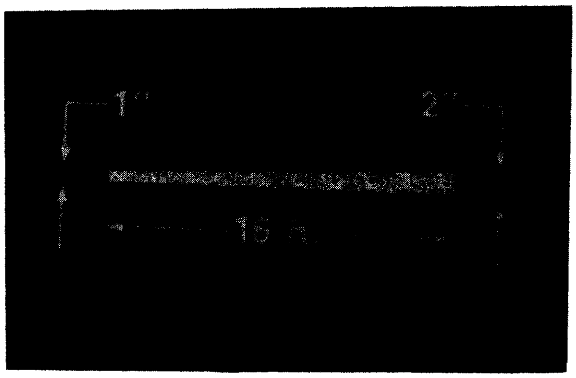
36. Thickened Mat
As an example of the operation of the sensor, a paver enters a shallow spot in the road, the grade sensor detects the fact that the tow point has dropped and signals for the mat to be thickened.



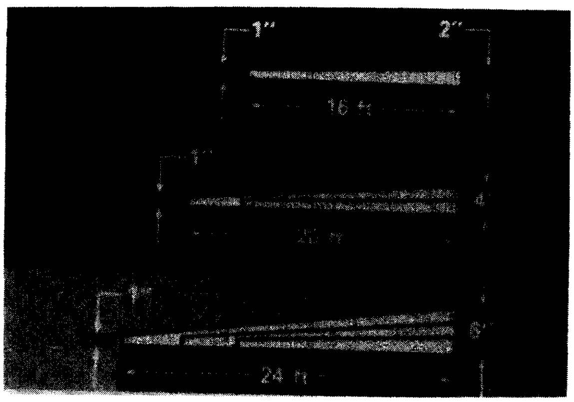
37. Results of Thickened Mat
The sensor readings are transmitted to the hydraulic control of the tow point ram. By raising the tow points, the angle of the screed is altered to bring about the necessary change in mat thickness.



38. Cross-Slope Control
The cross-slope of the pavement is controlled by the movement of the tow-point ram on the side of the paver opposite the grade sensor side. A pendelum mounted on a beam senses the difference in elevation between the beam ends. This cross-slope controller signals the tow point ram so that the screed may be maintained at the desired cross slope.

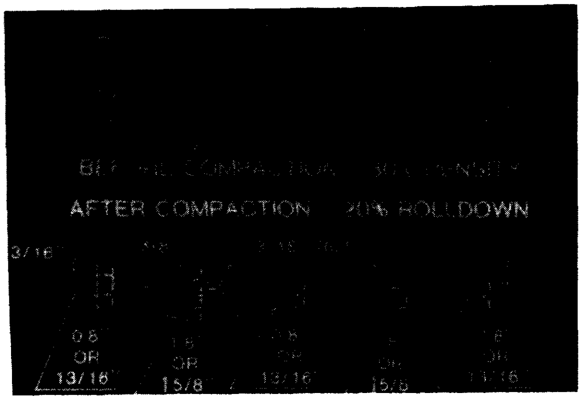


39. Superelevation and Wedge Sections
In addition to making it possible to place pavement to a precise grade, automated screed controls have greatly simplified the incorporation of superelevation in curves, where the superelevation is to be accomplished with an asphalt layer of varying thickness.

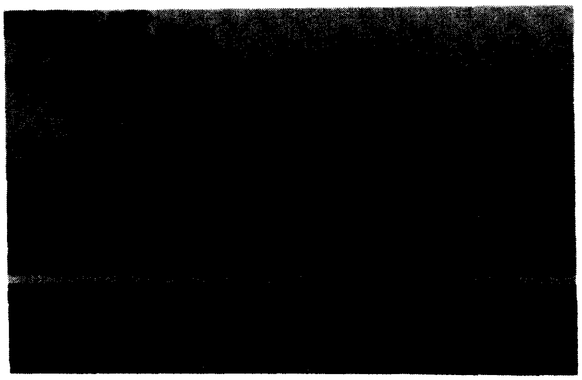


40. When greatly increasing the superelevation of a curve, the recommended practice is to place successive wedges which are thicker on the outside edge than on the inside edge. This slide shows the proper construction method.

An important consideration is the roll-down of the wedge layers. The amount of roll-down should be considered and incorporated into the laydown thickness.

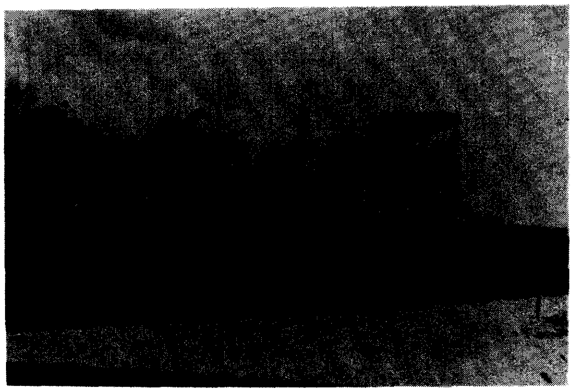


41. Rutted Section and Level Up
The rolldown during compaction must be considered when paving over a rutted section. As shown is this slide, a 1½" overlay of a rutted section will provide approximately 1" mat thickness between the wheel paths and 2" in the wheel paths. The paver screed consolidates the material and initially compacts the mat to about 80% of the target density. The other 20% is obtained by the compaction rollers. This 20% rolldown of the additional inch thickness in the rutted wheel path section will result in a 3/16" rut immediately after compaction. Therefore, a level-up course should be used on severly rutted sections or any place where variable mat thicknesses will occur. Many times the contractors want to place the level-up course as a portion of the regular overlay. This should not be allowed, as only successive lifts will eliminate the rutted or unlevel sections. Also note that level-up courses on a rutted section must be rolled with a rubber tired roller to compact the rutted section. The steel wheel roller will bridge over, and not properly compact, rutted sections. However, this additional compaction in the rutted sections will probably occur soon after the sections are open to traffic. Again, the rubber tire roller is the only type roller that is capable of compacting a mat with a variable thickness, such as a rutted section, or level-up courses.

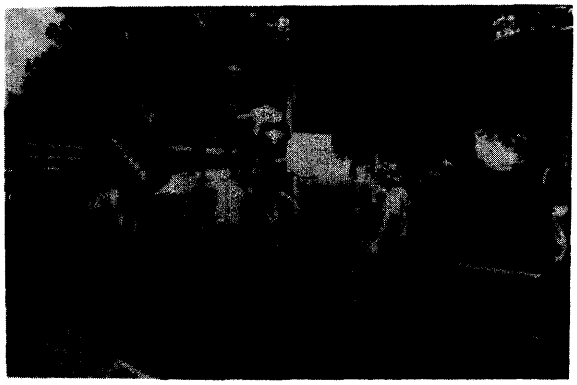


42. Joints
A cold longitudinal joint usually results in a crack which allows the entrance of water into the base or subgrade. Where possible and feasible, the cold longitudinal joint should be eliminated.

On some projects, especially large projects on new construction, two or more pavers may be used and operated one just behind the other to place the full width pavement. This procedure eliminates the cold longitudinal joint.

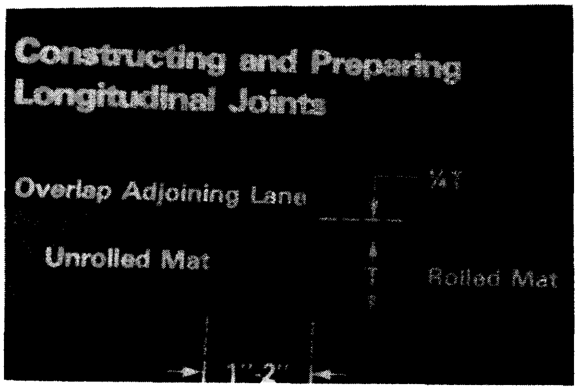


43. Full Width Paving
There are pavers on the market today that are capable of paving two or three lane highways full width. However, this type paving operation can only be used on new construction or where traffic does not have to be maintained.

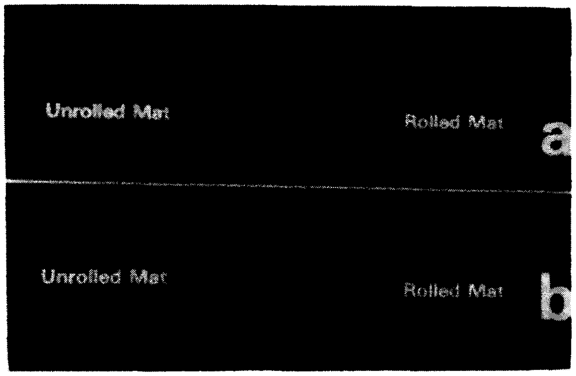


44. Paving Under Traffic
But on many small jobs and jobs where traffic must be maintained, only one paver can be justified, making a cold longitudinal joint necessary.

45. Cold joint construction will generally result in a lower density in the mat adjacent to the joint in the lane placed first. This lower density area is generally subject to earlier distress because of the high voids and greater permeability.



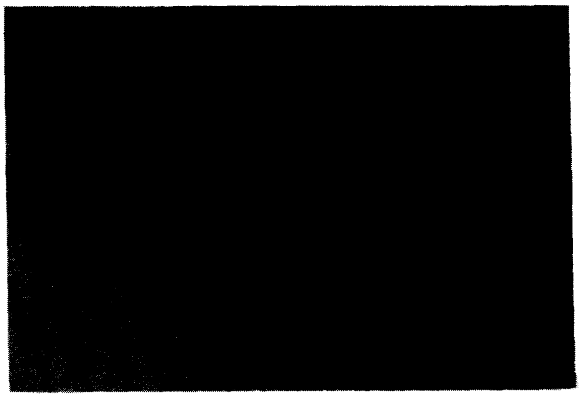
46. Joint Construction
There are two methods commonly used to construct longitudinal joints. The traditional method is to build a nearly vertical joint. A new method is to build a sloped joint with about a 4 to 1 horizontal to vertical slope. This joint is compacted with a rubber-tire roller to result in the same density as the adjacent mat. This slope allows traffic to cross the joint easier on thicker lifts. Proper care and correct techniques in preparing and constructing either of these longitudinal joints will help ensure a durable maintenance free joint. The amount of overlap should not exceed 2". Note that the unrolled mat should be about ¼ thicker than the rolled mat to allow for the rolldown.



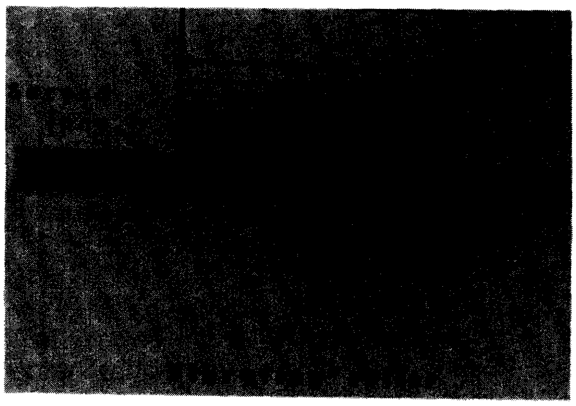
47. Joint Preparation
There are two techniques used for constructing longitudinal joints. One is to crowd the overlapped mix back into a humped ridge of uniform size so that the breakdown roller can press this small excess into the hot side of the joint. Another is to simply remove or trim the lapped material. The traditional vertical joint can be built using either technique while the sloped joint should be built only by crowding the overlap.

48. Joint Trimming
A trimmed longitudinal ~~joint~~ is constructed by removing all the freshly lapped material. This material should not be broadcast over the surface of the unrolled mat.

49. Joint Construction
This slide shows a crowded joint being properly constructed.

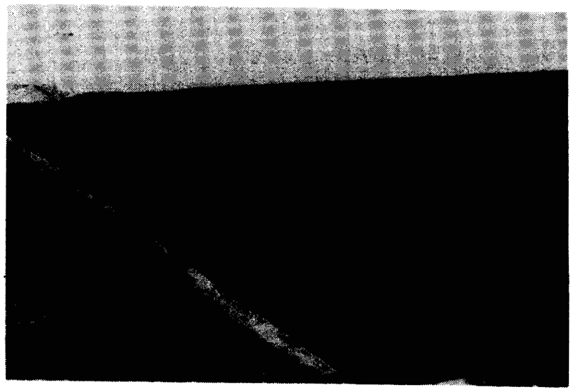


50. Static Roller on the Joint
Because of the need to get as good a longitudinal joint as possible, during compaction this joint should be rolled first. However, the proper joint rolling technique varies significantly with the type roller being used. As shown in this slide, if a static roller is being used it should run on the compacted mat with approximately a 6" lap on the hot uncompacted mat.

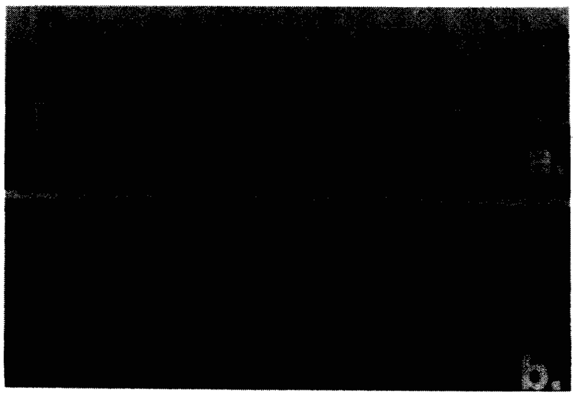


51. Vibratory Roller on Joint
If a vibratory roller is being used, it should be run mostly on the hot mat with approximately 6" overlap on the compacted mat. It is very important to remember that the vibratory compactor should never be operated on the compacted mat. In almost all cases the vibratory roller will cause decompaction of the previously placed mat.

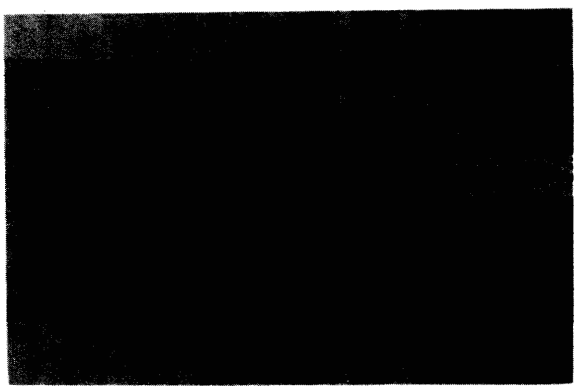
52. Alternate Joint Rolling Procedure
An alternate procedure for operating the vibratory roller, is to operate it entirely on the fresh mat, leaving a strip of approximately 3" wide at the joint. The 3" strip should then be compacted with the roller in the static mode. Again, the vibratory roller should never be operated on the previously compacted mat.



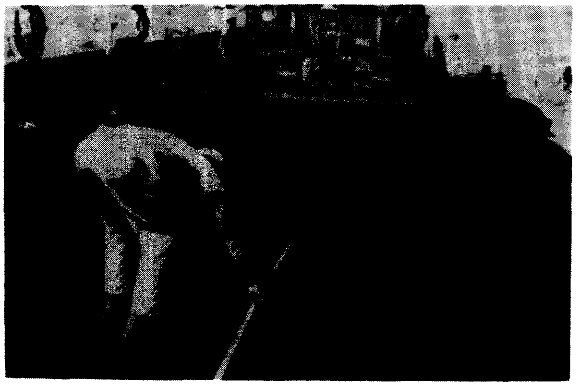
53. Tranverse Construction Joint
The construction of a good transverse joint is just as important as a good longitudinal joint. The most widely used method for making construction joints, as shown in this slide, is to place building paper or roofing felt, then place a temporary ramp of hot-mix.



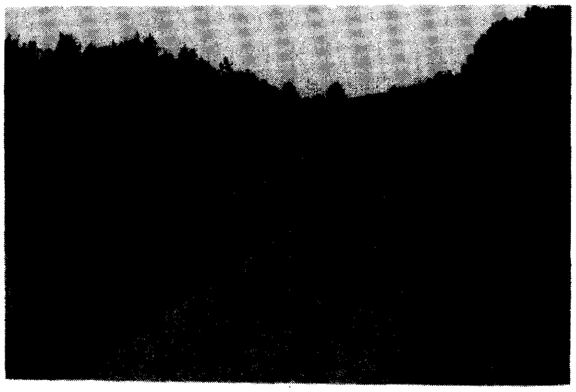
54. When work begins again, the ramp and portion of the mat over the building paper are removed and replaced with the new mat of hot-mix.



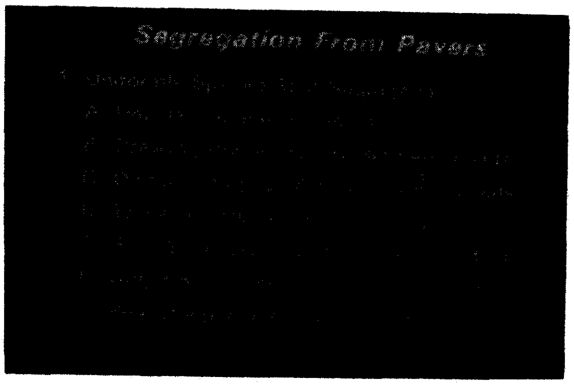
55. Rolling Transverse Joint
When compacting the transverse joint the roller should be operated perpendicular to the center line. Depending on the type roller being used, the rolling technique should be the same as previously discussed for the longitudinal joint. Note that timbers are placed on each side to allow the roller to operate fully across the pavement width.



56. Straight Edge Joints
Regardless of the method used to construct the transverse joint, it must be carefully checked with a straight edge. If it is not true and smooth, the full thickness of the mat should be removed far enough back to make corrections. Then after initial compaction, the joint should again be checked with a straight edge. Any deficiencies should be corrected immediately. The paving train should not move on until the transverse joint is correct.



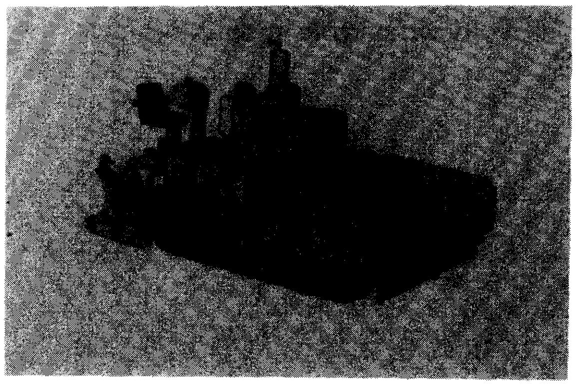
57. Good equipment and its proper operation is essential to transport and place asphalt hot mix. Construction techniques are constantly changing and as a result we often see segregation in the pavements. Segregation can occur in the stockpiling and handling of the aggregates, in the plant operations, or in the laydown. Regardless of the source, the result will be seen immediately behind the paver. Two of the most common types of segregation can be seen in this slide as linear segregation and spot segregation.



58. Segregation can be caused by improper paver operation. Some likely contributing factors are shown on this slide:

59. On a paving project normally the demand on one side of the paver is greater than the other. As a result material will remain in one side of the hopper while the other side runs empty. Then if material which is segregated in the truck is added to the hopper it naturally goes to the empty side of the hopper. Therefore, the spot segregation will usually occur on one particular side of the paver.

While it is not the most common cause, a large imbalance in the paver demand on one side can result in the spot segregation. This can be noted when one side of the hopper runs empty while material is heaped up on the other side. When one side of the hopper is being pulled empty, the material moves in a swirling eddy type action and segregation can readily be seen. This overdemand of material on one side of the paver usually occurs when the paving width is extended on only one side instead of being balanced on each side and/or when the mat thickness is not uniform across the pavement width. As shown in this picture, the wing area of the hoppers on the older model laydown machines used to be sloped. By being sloped they provided a degree of self-cleaning.



60. Picture of Laydown Machine
In efforts to increase the storage capacity of the hopper, most manufacturers of laydown equipment have flattened the wing area. Note the wide flat ledge on the hopper of this new laydown machine. The hopper wings of this new machine consists of a wide flat ledge. These flat wings are not self-cleaning. The material is removed only when the wings are

dumped. Since the hopper is wider than a truck, material being unloaded from a truck only covers about the middle two thirds of the hopper width in more or less a cone shape. As the laydown machine is being operated, vibration occurs. As a result, the coarse mix particles trickle down the side of the cone and are deposited in the flat areas of the hopper wings. This segregated material remains in the hopper wings until they are dumped.

61. Dumping the Hopper Wings
The paver is equipped with two slat conveyers to move the hot mix material from the hopper to the augers at the rear of the tractor. These slat conveyors operate independently to meet the demand for material on their particular side of the paver. Also there is a divider separating the two slat conveyors. Because of the truck bed, the hopper wings can only be dumped between truck loads. As previously discussed, unless the material demand for each side of the paver is perfectly matched, one side of the hopper will run empty while material remains in the other side. If one side of the hopper is empty and the segregated material in the hopper wings is dumped, almost all of the material in the hopper wings is either dumped directly into or tumbles into the empty side of the hopper.

62. Dumping the Truck
If the material in the front and back of the trucks is segregated, the last material to be dumped from the previous truck and the first material from this truck is segregated and it ends up in the empty side of the hopper. Thus a segregated spot occurs at the end of each truck load.

Some steps to take in the truck operations to eliminate or reduce this uniformly spaced spot segregation are as follows:

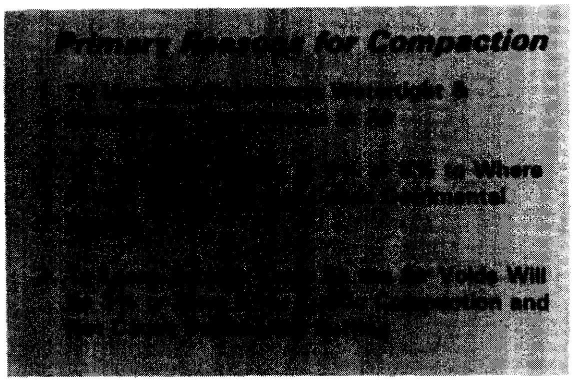
a. Load the trucks properly in multiple drops by moving it back and forth.

b. Don't release the tailgate until the truck bed is well on its way up so the entire load tends to slide out as one mass and completely fill the paver hopper.

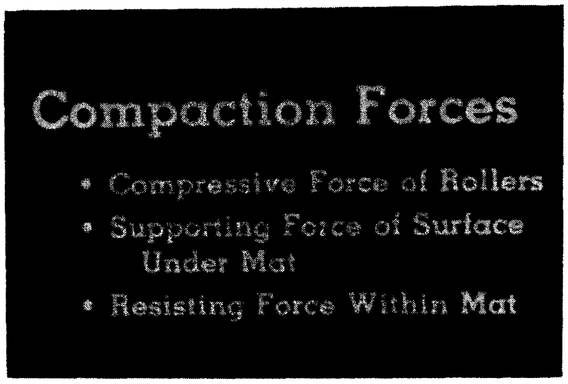
63. This concludes the laydown section of this presentation. In summary we have discussed the proper techniques for loading and transporting the mix, the operation of the paver, and several problems that may be experienced.

COMPACTION

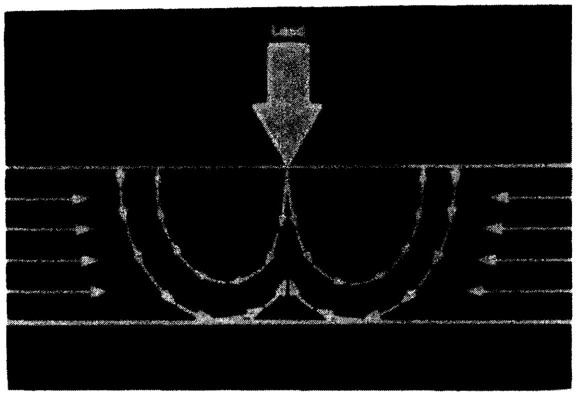
1. This section of the presentation will address the subject of compaction.



2. Primary Reasons for Compaction
   The primary reasons for compaction are:
   1. To make the pavement watertight and reasonably impermeable to air.
   2. To reduce the voids to the 6 to 8% range where future traffic will not cause detrimental rutting due to consolidation.
   3. To provide sufficient voids, 3% or more, so that traffic consolidation will not cause detrimental rutting.



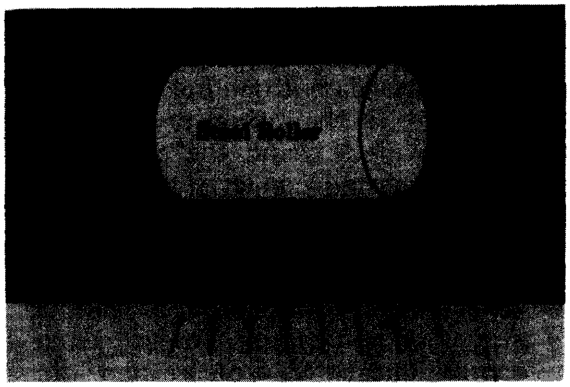
3. The compaction process involves three forces. They are:
   1. The compressive force of the rollers.
   2. The supporting force provided by the stable surface beneath the mat.
   3. The forces within the mix that resist the force of the rollers.



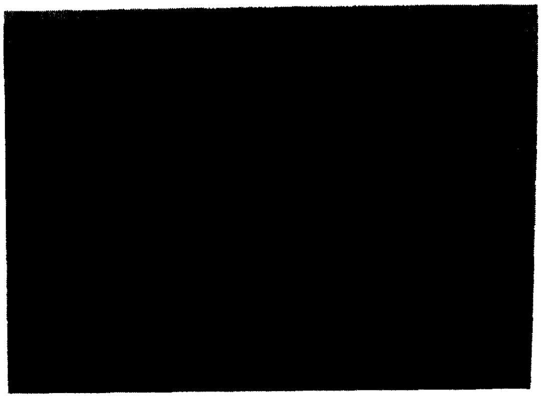
4. Flux Lines of the Load on the Mat
This slide illustrates the path of the lines of force in an asphalt mix resulting from an applied load. It can be seen that the path of the forces is approximately circular.

In order to compact an asphalt mixture it is absolutely necessary for the mix being compacted to be confined. The confining forces present in an asphalt mixture during the compaction process as illustrated in this slide are:

1. The large arrow represents the load applied by the roller whether it be a steel wheel or rubber tired roller.
2. The inner-curved line of arrows directly under the large arrow represents the line of forces and their paths within the mix resulting from the applied load.
3. The outer-curved line of arrows represents the forces within the mix resisting the movement of particles. These forces result primarily from the inter-particle friction of the aggregate particles in the mix. The binder made up of asphalt and fines also contributes to this resisting force. As the temperature of the mix decreases the resisting forces contributed by the binder increase.
4. The horizontal arrows respresent the confinement provided by the layer of mix itself. This confining pressure increases as compaction proceeds and density is achieved.

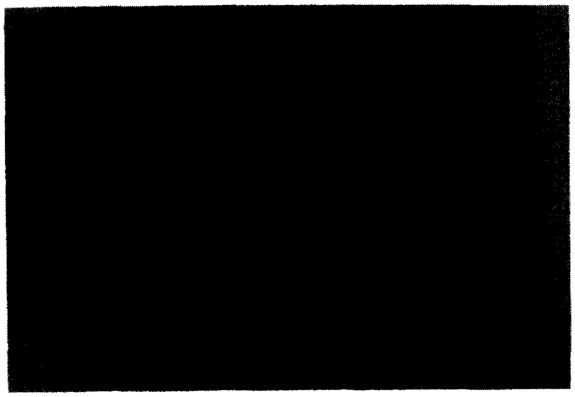


5. Steel Wheel Roller Forces
This slide illustrates the line of forces in an asphalt mixture under the action of a steel wheel roller. Except for the two outer arrows, the remaining lines of force are resisted either by the subgrade or by the confinement within the mix itself. The two outer arrows follow a circular path and represent the forces coming from the edge of the roller drum. These forces are contained entirely in the layer of the mix. As seen in this slide, the succeeding passes of the roller need to overlap only enough to compact the mix that might have been up-thrust by the forces represented by the two arrows coming from the edge of the roller. Thus the roller needs to overlap only a few inches.



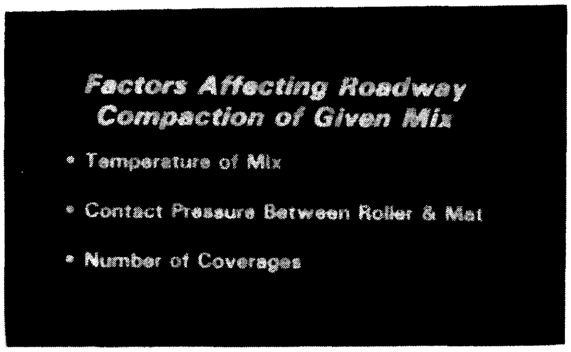
6. Contact Area
Density produced during static rolling is related to contact pressure between the roller and the mat rather than the overall weight of the roller. This is because the contact pressure is controlled by the characteristics of the mix.

This slide shows the effects of roller weight. The mix has a bearing capacity of 50 PSI and the drums are identical in diameter and width but one is loaded to 8,000 pounds while the other is loaded to 12,000 pounds. Because the mix can only support 50 PSI, note that the 8,000 pound drum must sink into the mat approximately 3/64 of an inch to get the required 2.96 inches contact. Under the same conditions the 12,000 pound load must sink approximately 7/64 of an inch to obtain the 4.44 inches of contact.

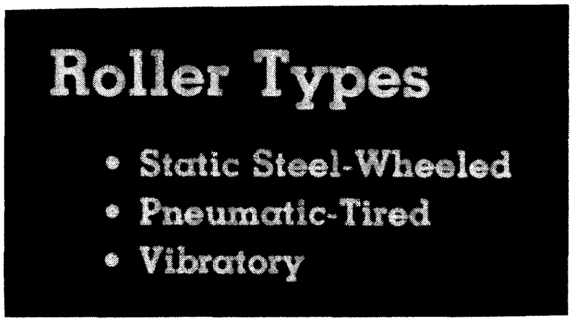


7. In this slide the drums have the same diameter and are loaded to 12,000 pounds but one has a 54 inch width while the other drum is 84 inches wide. Using the same mix with a bearing capacity of 50 PSI, note that the 54 inch drum has to sink into the mix approximately 7/64 of an inch to get the needed 4.44 inches of contact. The 84 inch wide drum must sink approximately 3/64 of an inch into the mix to get the 2.86 inches of contact. Therefore, we can see that rollers with wider drums can get on a mat hotter than a narrower drum.

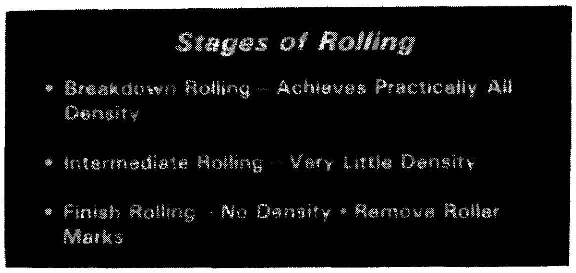
   The same principle applies to drum diameter. The larger the diameter the less the roller will sink into the mix and the hotter the mat can be rolled.



8. Factors Affecting Compaction of a Given Mix
   The factors affecting the roadway compaction of a given mix are: (1) the temperature of the mix; (2) the contact pressure between the roller and the mat; and (3) the number of coverages.

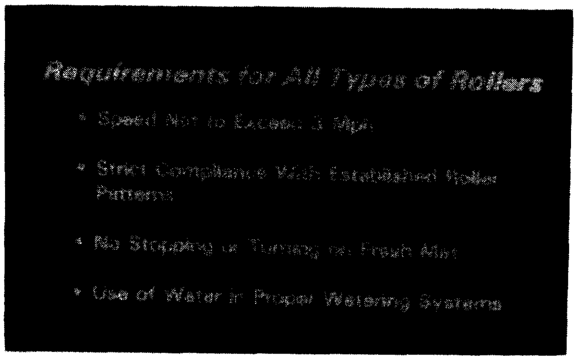


9. The three types of rollers generally used for compaction are the Static-Steel Wheeled, the Pneumatic- or Rubber-Tired, and the Vibratory.

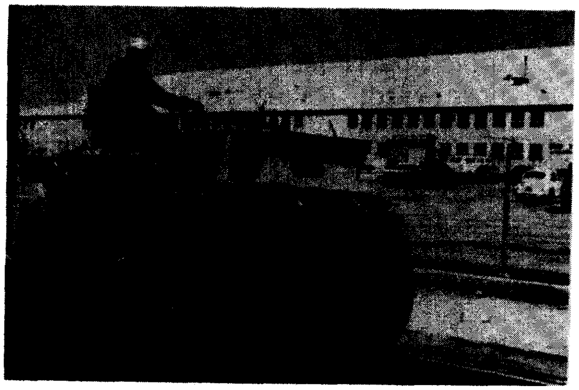


10. Stages of Rolling
    The three stages of rolling are: (1) breakdown rolling where practically all of the density is

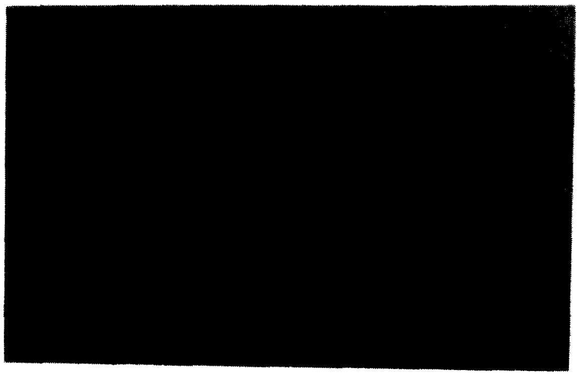
achieved; (2) the intermediate rolling where a little additional density is achieved; and (3) the finish rolling which is used to remove roller marks and finish the surface. There is practically no additional densification in this last stage. The compaction of a mat must be completed while the temperature of the mix is about 175^{o}F or higher.



11. Requirements for All Rollers
The following are requirements for all types of rollers: (1) the maximum speed for any type roller should not exceed 3 miles per hour to keep from shoving the mat; (2) strict compliance with established roller patterns; (3) no stopping or turning on the fresh mat; and (4) use of water in a proper watering system.

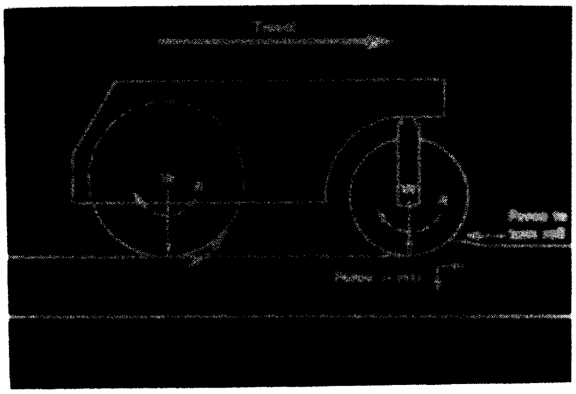


12. Picture of Steel Wheel Roller
The steel wheel roller has been used to compact many miles of asphalt pavement. It has historically been the work horse of compaction. It's operation is simple and it still functions well today.

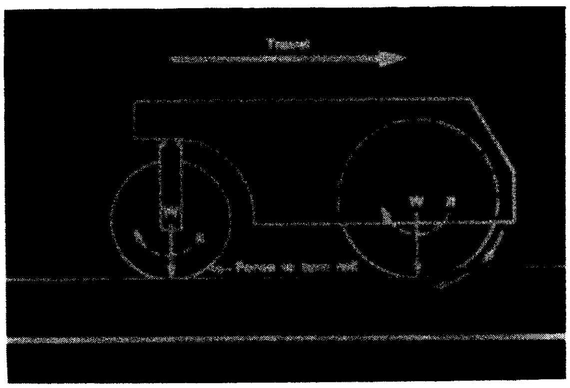


13. Highest Possible Temperature for Steel Wheel Roller
In most cases, we want to compact the mat at the highest temperature possible. The behavior of the mat under the roller is the best measure of this temperature. In this slide note that when the mat is too hot, a large roll is produced in front of the roller with surface cracks. If the mat is too cold, there is no roll at all in front of

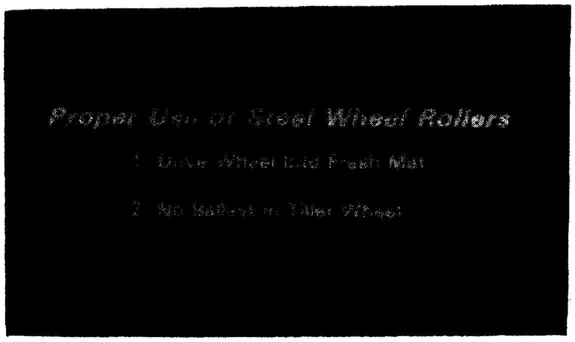
the roller. However when the mat is at the highest temperature possible there is a slight roll in front of the roller with no cracking.



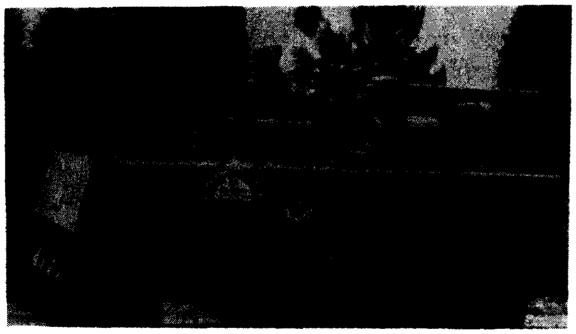
14. Wrong Direction of Travel for a Steel Wheel Drum
This slide illustrates a steel wheel roller being used incorrectly on asphalt mixture. Note that in this direction of travel, the tiller wheel is in front. Since there is no mechanical rotation forces on the tiller wheel, it is a dead wheel. Therefore, when the tiller wheel is in front there is a tendency for the drum to push the mix away from itself causing a roll in front of the wheel. Therefore, the resultant of the vertical force and the horizontal resisting force is somewhat ahead of a true vertical downward force. For the purpose of compaction of a mix the desirable direction of movement of all particles is vertically downward. Very little, if any, compaction occurs in the mix as a result of horizontal movement in the mix. Such a horizontal movement can result in a reduction in density even after the mix has been compacted.



15. Right Direction of Travel
Every effort should be made to minimize the horizontal movement of the mix during compaction. This slide illustrates the proper use of the steel wheel roller. In this direction of travel, the drive wheel is on the uncompacted mix first with the tiller wheel following. The rotational force of the drive wheel tends to tuck the mix under the roller rather than pushing it away. The result of these forces is more nearly a direct vertical force.



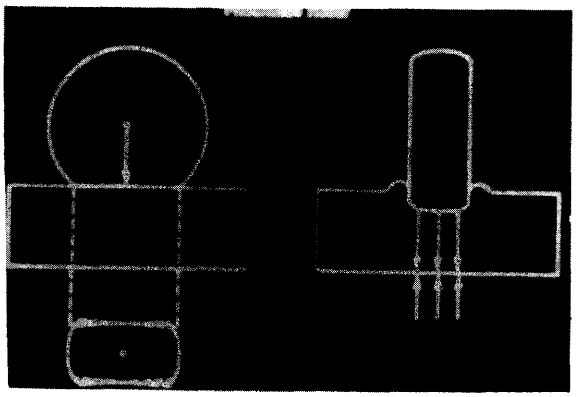
16. Proper Use of Steel Wheel Roller
Proper use of the steel wheel roller includes: (1) the drive wheel should always be first to the fresh mat; and (2) there should be no ballast in the tiller wheel.



17. Picture of a Rubber Tired Roller.
The rubber tired or pneumatic roller is the second type that will be addressed.

18. Rubber tired rollers have the following unique features:

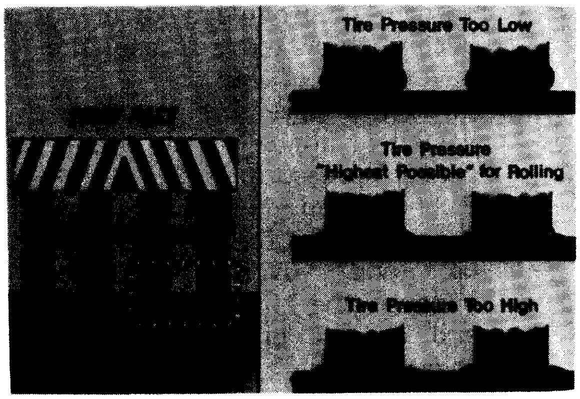
a. The tires are flexible and they deform to provide a kneading action which tends to seal the pavement surface.
b. The tire pressure can be varied to adjust to the proper contact pressure.
c. Rubber-tired rollers are recommended for use on level-up and overlay courses because the tires will deform and do not bridge over low areas.



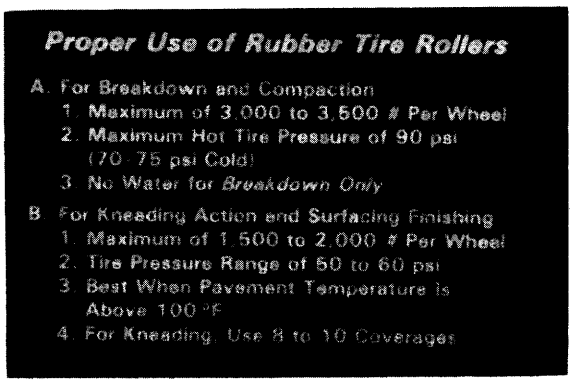
19. Rubber Tired Roller Forces
This slide illustrates the actions of the rubber tired roller when used either for breakdown or intermediate rolling. The sketch on the left is intended to illustrate the kneading action of the tires on the compacted asphalt surface, while the sketch on the right illustrates the forces that are acting on the rubber tire during

compaction. Under normal conditions, when the rubber tired roller is on top of a firm mass it has practically no horizontal thrust on the pavement. The reason is that the rubber tire flattens on the bottom permitting almost a 100% vertical downward force. As with the steel wheel roller, it is absolutely necessary for the mix being compacted to be adequately confined in order for the rubber tired roller to achieve density in the mix.

20. Highest Temperature Possible for Rubber Tired Roller
As with the steel wheel roller, the behavior of the mat under the rubber tired roller is the best measure to determine the highest compaction temperature possible. Note that with the rubber tired roller the roll is to the side of the roller wheels and not in front of the roller.



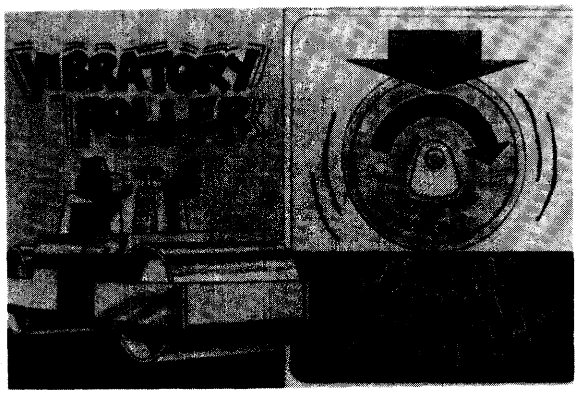
21. In order to get proper compaction with a rubber tired roller, the tire pressure should be adjusted to the highest possible for the particular mix. This pressure is determined by observing the behavior of the mat on the first pass as shown.



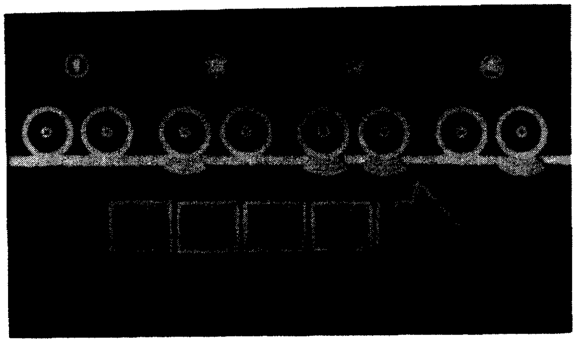
22. Proper Use of a Rubber Tired Roller
The proper use of the rubber tired roller for breakdown and compaction includes the following:

(1) a maximum of 3,000 to 3,500 pounds per wheel; (2) a maximum tire pressure of 90 PSI hot which is about 70 to 75 PSI cold; and (3) no water for breakdown rolling. If the rubber tired roller is to be used for breakdown rolling the tires must become as hot as the mix being compacted.

The proper use of a rubber tired roller for the kneading action and surface finishing includes the following: (1) a maximum of 1,500 to 2,000 pounds per wheel; (2) a hot tire pressure of 50 to 60 PSI; (3) the best results are obtained when the pavement temperature is above 100°F; and (4) for the kneading action use 8 to 10 coverages.



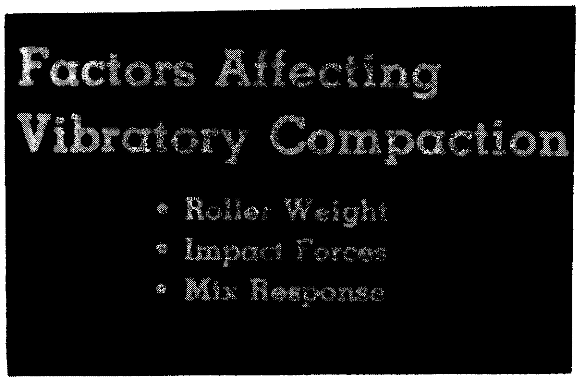
23. Vibratory Roller Forces
The other type roller in common use today is the vibratory roller. The vibratory roller does not compact by vibration, but rather by impact. A rotating eccentric weight in the drum produces the vibration. The energy imparted to the mix is mainly from impact and weight. Most vibratory roller controls provide adjustment of both the frequency and amplitude of the impact. The amplitude controls the amount of energy imparted to the mix by each up and down movement of the eccentric weight. As shown in this slide, these impacts produce pressure waves that pass through the mix. This pressure wave aids in overcoming interparticle friction. Under normal conditions, the vibratory roller can compact a mix in fewer passes than the static roller.



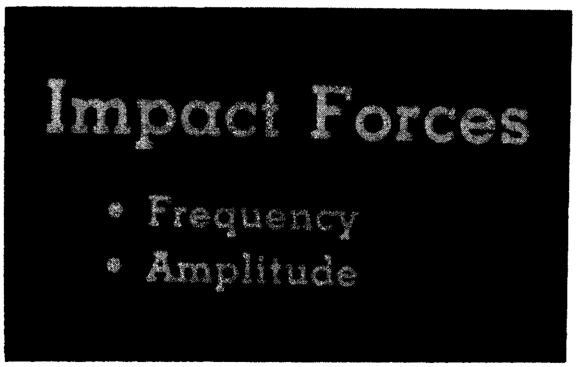
24. Vibratory Roller Modes
There are several reasons for the popularity of the vibratory rollers:

(1) they normally accomplish the desired compaction in fewer passes; and (2) a dual drum vibratory can be operated in 4 different modes. They can be operated completely static, with one drum static and the other vibrating, or with both drums in the vibratory mode. Thus, the vibratory roller can be used for all three compaction stages, breakdown rolling, intermediate rolling, and finish rolling.

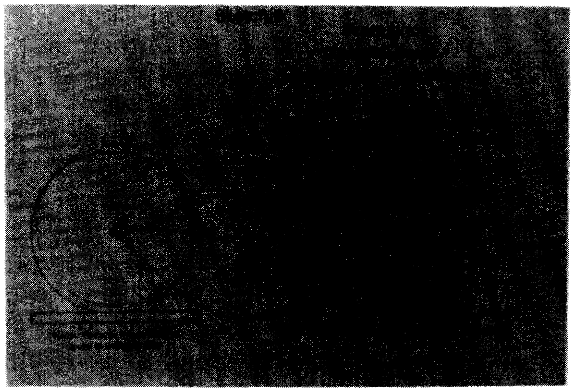
While it is standard with the new vibratory rollers and probably with all vibratory rollers used today, it is essential that the eccentric rotation be in the direction opposite the drum movement. If the eccentric rotation is in the same direction as the drum, it will tend to tear and pull the mix apart.



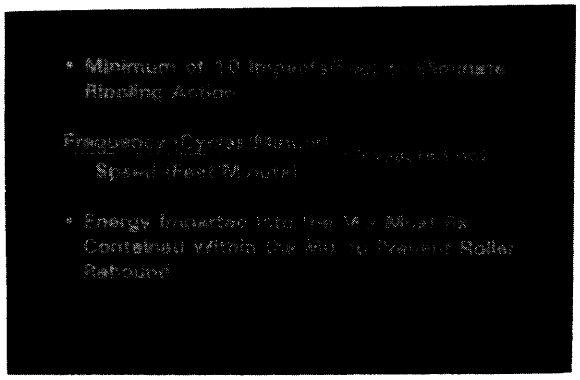
25. The major factors in providing proper compaction of a mix with a vibratory rollers are the weight of the roller, the magnitude of the impact force, and the response of the mix itself.



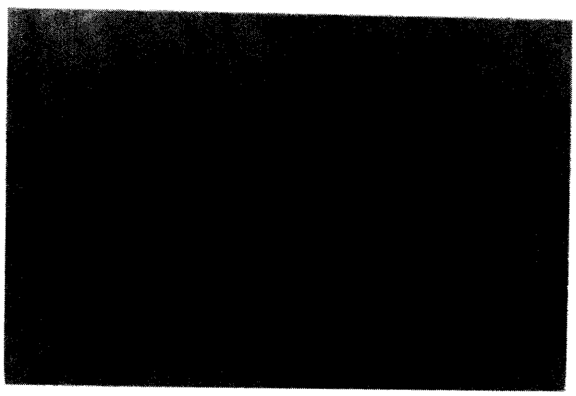
26. Frequency and Amplitude
When discussing vibratory rollers, the terms frequency and amplitude are important.



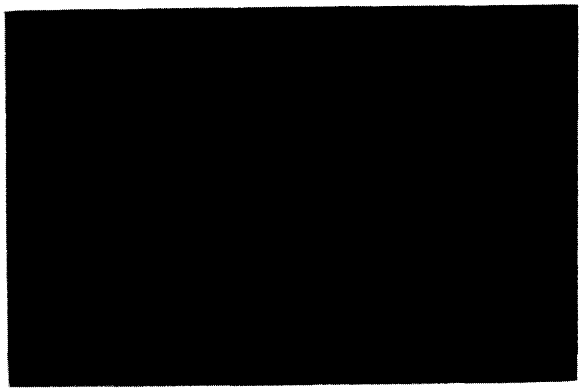
27. Frequency is the number of times the drum bounces and is expressed in cycles per minute. Amplitude is how high the drum bounces and is expressed in fractions of an inch or millimeters. All vibratory rollers should be capable of adjusting the amplitude from low to high.



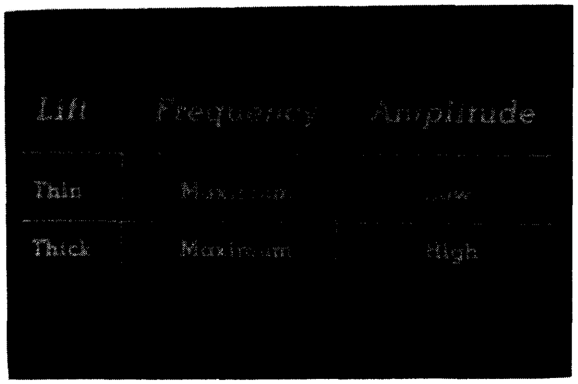
28. Impacts Per Foot Calculations
It is generally agreed that a minimum of 10 impacts per foot is needed to eliminate the rippling action of the vibratory roller. Although the amplitude of a roller is adjusted, normally the roller is operated at a high frequency and the speed of the roller is adjusted to produce the desired minimum number of impacts per foot. The impacts per foot are calculated by dividing the frequency in cycles per minute by the speed in feet per minute. When adjusting the roller speed, frequency, and amplitude, it is important to remember that the energy imparted to the mix must be contained within the mix to prevent roller rebound. Normally on thin mats in the range of $1\frac{1}{2}$-2 inches, low amplitude is used. On thinner mats or sand asphalt mixes it may be necessary to operate the vibratory roller completely in the static mode.



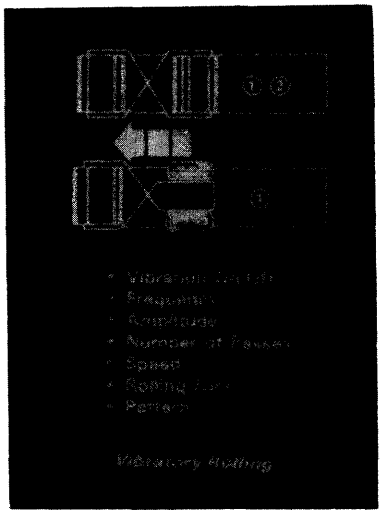
29. Impacts Per Foot Diagram
Illustration of Impacts Per Foot
This slide illustrates a vibratory roller operating at 2.5 miles per hour or 220 feet per minute and operating at frequencies of 1,400 cycles per minute and 2,200 cycles per minute. Note that at a frequency of 1,400 cycles per minute 6.4 tamps or impacts per linear foot is produced. At a frequency of 2,200 cycles per minute 10 tamps per linear foot is produced.



30. Frequency versus Speed Chart
This table gives the impacts per linear foot at various frequencies and various roller speeds. Note that approximately 3 miles per hour or 264 feet per minute is the maximum speed at which the minimum of 10 impacts per foot can be produced. If the minimum impacts per foot are not being obtained, the frequency must be increased or the speed of the roller decreased.



31. As was discussed earlier, the energy imparted to the mat must be contained within the mat to prevent roller rebound and decompaction. This illustrates that the amplitude of the roller must be adjusted based on the thickness of the mat being placed. Once a mat is decompacted due to over rolling with a vibratory roller, it is very difficult to regain the desired degree of density.



32. Vibratory Roller Variables
In determining roller passes, one pass of a dual drum roller counts as two passes. When working with a vibratory roller several variables are very important in its operation. These variables are:

a. Vibration On or Off. Is the machine being operated in a vibratory mode or a static mode or a combination of vibratory and static modes?

b. Frequency. Is the frequency proper to obtain the desired number of impacts per foot?

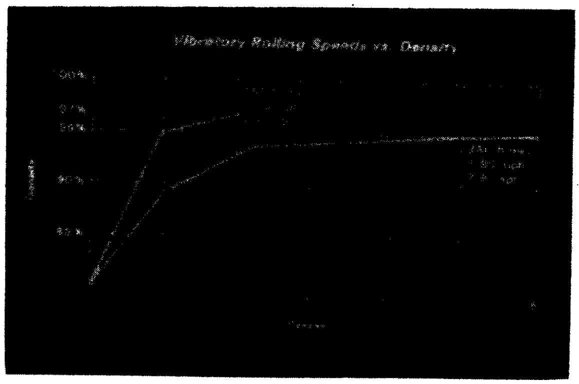
c. Amplitude - Is the amplitude proper for the type mixture and lift thickness?

d. Number of passes - Is the vibratory roller making only the number of passes needed and no more or less? The number of passes when using a vibratory roller is very important, as decompaction can occur with only one additional pass.

e. Speed - Is the speed matched to the frequency to obtain the desired number of impacts per foot? Also, if one is having difficulty obtaining compaction, the speed of the roller should be slowed down.

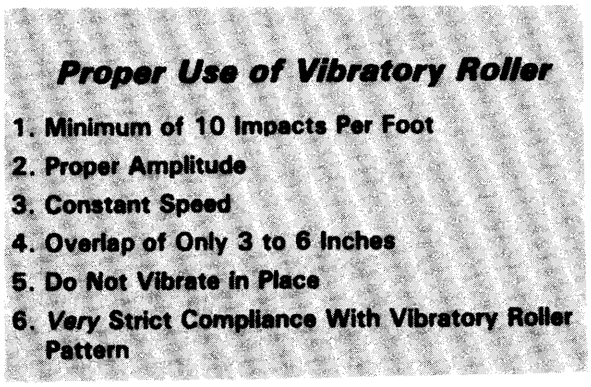
f. Roller Zone - This is the zone or length of pavement behind the paver in which the compaction process is taking place. This can vary from very close to the paver to several hundred feet behind the paver, depending on mix characteristics and environmental conditions.

g. Pattern - The roller pattern is very critical in a vibratory operation. In establishing a roller pattern it is essential that the vibratory roller not overlap the previous pass by more than 6 inches.



33. Vibratory Speed Versus Compaction
There seems to be a general tendency for all roller operators to speed up the roller as the day progresses. This is especially true if they get a little behind in their compaction work. With the static roller they would speed the roller

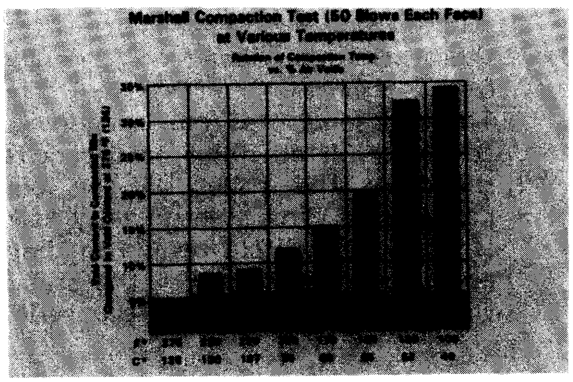
up a little to catch up. However, if you speed up a vibratory roller you obtain less compaction because the number of impacts, or energy per linear foot, is less. You need to slow down the vibratory roller to increase the compactive effort. However, this is very difficult to explain to a long-time static roller operator. As shown in this slide a vibratory roller operated at 150 feet per minute obtains 97% density in two passes. The same roller operated at 250 feet per minute only obtains approximately 95% compaction in 6 passes.



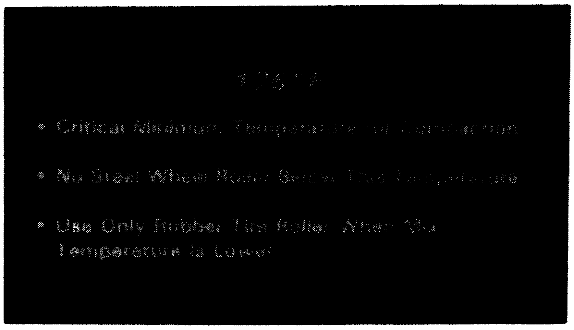
34. Proper Use of Vibratory Roller
The following are some guidelines that should be followed for the proper use of the vibratory roller.

a. A minimum of 10 impacts per foot.
b. The proper amplitude to match the mat thickness.
c. Maintain a constant speed at all times.
d. Should overlap only 3 to 6 inches.
e. Do not vibrate in place.
f. Maintain very strict compliance with vibratory roller patterns.

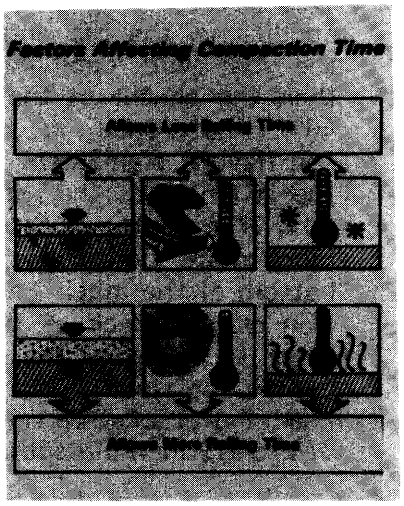
35. In the use of any of the roller types presented here, it is essential that compaction be completed while the mat is hot.



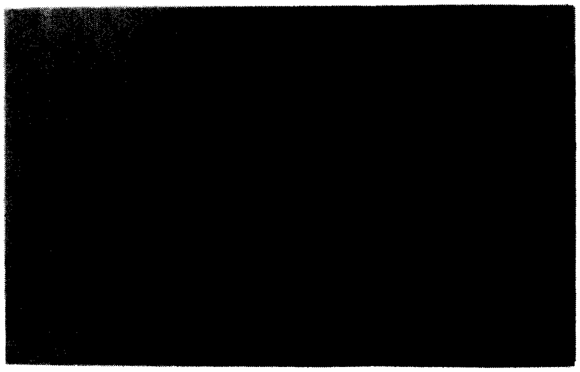
36. Temperature versus Compaction Bar Graph
As noted in the mix design section, the temperature of this particular mix must be in excess of 200°F if it is going to be compacted to less than 10% voids.



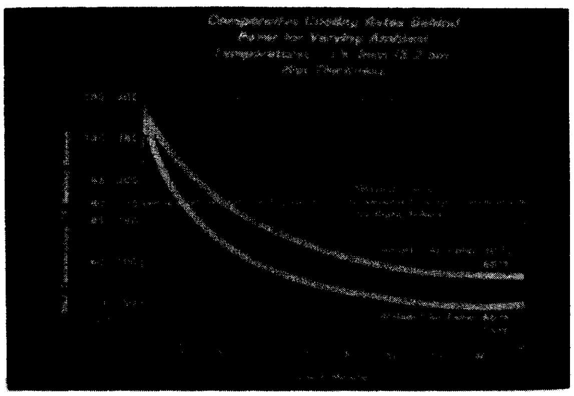
37. 175°F is the critical minimum temperature for compaction. No steel wheel roller should be allowed on the mat when the temperature is below 175°F. The use of vibratory rollers on a mat below this temperature can cause serious decompaction of the mat. The rubber tired roller is the only type roller that should be allowed on the mat when the temperature is below 175°F.



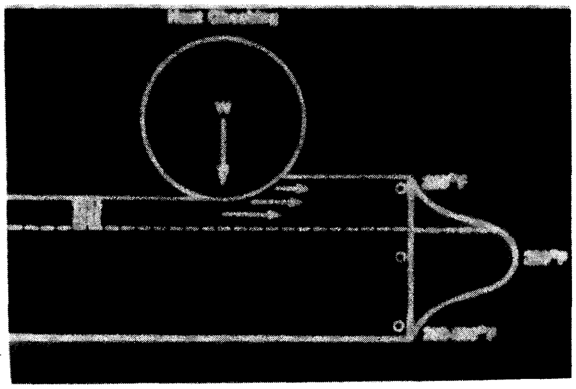
38. The rate of cooling or the allowed compaction time for the mat is dependent on mat thickness and the ambient and base temperatures. When placing hot mix during the fall, winter and spring months, the environmental factors can have a dramatic effect on the cooling rate and compaction time for a mix. This change can be on a daily basis or even an hourly basis.



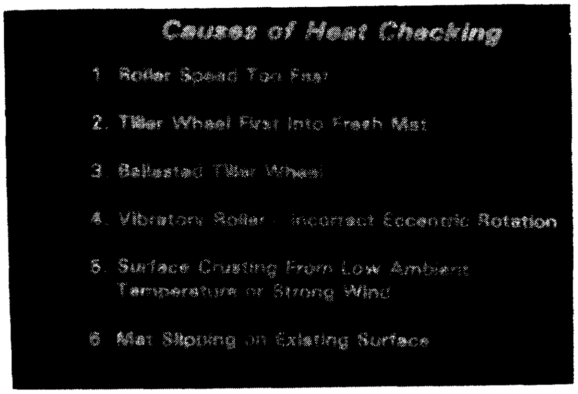
39. Compaction Time versus Temperature Chart
As shown in this chart the base temperature and mat thickness have a major effect on the allowable compaction time. Caution should be exercised when placing a thin mat during a cool part of the season or during winter months.



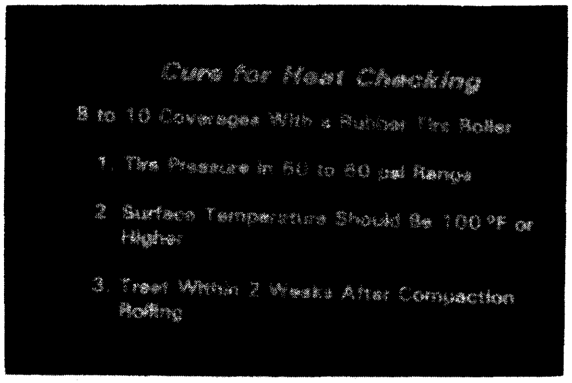
40. Compaction Time versus Temperature Curve
This graph shows that reducing the ambient temperature from 86°F to 55°F reduces the compaction time from 20 minutes to 10 minutes before the mix reaches 175°F.



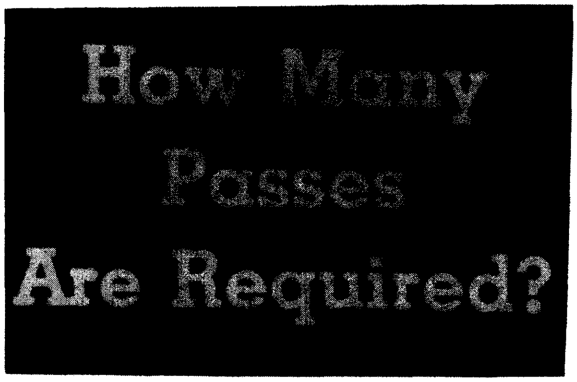
41. This slide shows what is commonly known as Heat Checking.
Analyzing a temperature profile of the pavement during rolling may aid in understanding how heat checking occurs. This temperature profile shows the center of the mat to be approximately 290°F while the surface has cooled to approximately 260°F and the base has cooled to the 250-260°F range. This is true in almost all laydown conditions, the top and bottom of the mat will cool more quickly than the center of the mat. This 40°F difference in temperature can have a significant effect upon the stiffness of the asphalt in the mix. The center of the mat will be much more fluid than the top and bottom of the mat. Therefore, the thin stiff surface of the mat will tend to slip on the more fluid center portion. Normally heat checking cracks are not more than 3/8 to 1/2 inch in depth.



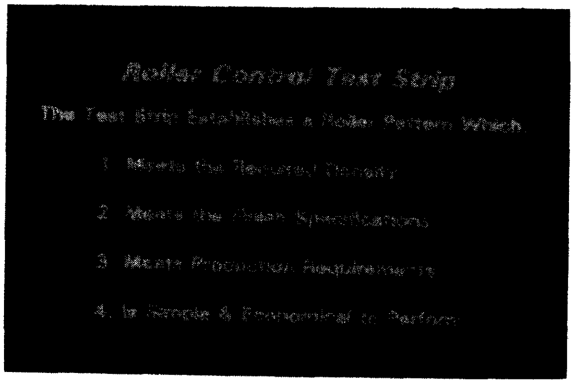
42. Causes of Heat Checking
Some of the causes of heat checking are:
1. Roller speed too fast.
2. Tiller wheel first to fresh mat.
3. Ballast in tiller wheel.
4. Vibratory roller with incorrect eccentric rotation.
5. Surface crusting from low temperature or strong wind.
6. Mat slipping on the existing surface, which would produce a crack all the way through the mat thickness.



43. Cure for Heat Checking
When heat checking cracks occur they can be cured with 8 to 10 coverages of a rubber tired roller. The tire pressure should be in the 50 to 60 PSI range. The surface temperature should be 100°F or higher for best results. Such a section can be treated up to 2 weeks after construction.

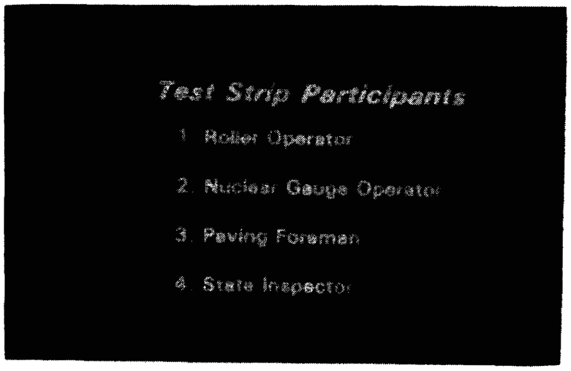


44. We've examined the importance of performing the compaction operations while the pavement is hot in order to obtain the proper density. Now we will discuss procedures to assure that density is obtained. All medium and high traffic volume highway projects should begin operations with a test strip for each type of hot mix placed. The roller test strip only has to be a few hundred feet in length, but many factors can be determined that are essential in the construction of the pavement. A test strip requirement should be a part of all specifications.



45. Purpose of the Test Strip
The purpose of the test strip is to establish a rolling pattern for the specific types and number of rollers to be used during the project for that given mix design. Any change in the mix design, roller type or number, or underlying support will require a new test strip. The test strip establishes a roller pattern which:

1. Meets the required density.
2. Meets the finish specifications.
3. Meets production requirements.
4. Is simple and economical to perform.



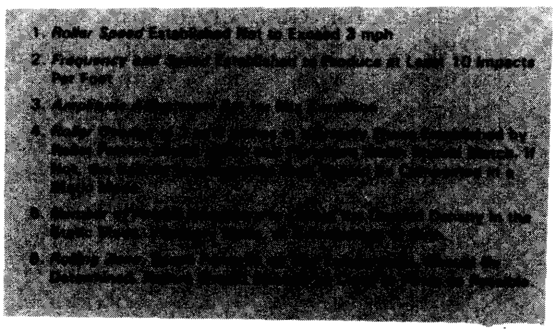
46. Test Strip Participants
There are several preliminary determinations that should be made prior to actually constructing the test strip.

a. Prior to paving the project should be reviewed to determine the different widths of pavement that will need to be placed. Many times the ramps and intersections are a different width than the main lane pavement.

b. The participants need to check the roller to see that it is operating properly, all essential gauges are operating and that the watering system and pads for cleaning the wheels are in good operating conditions.

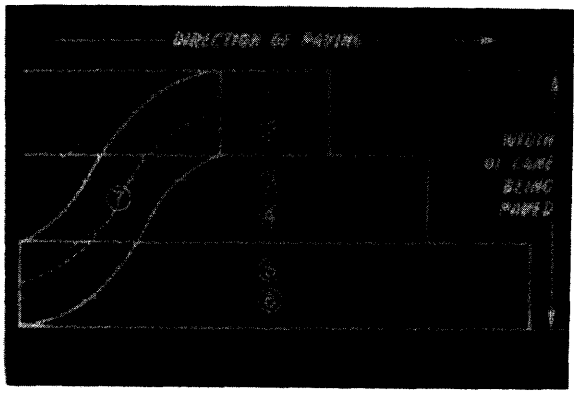
c. The test site should be selected and any staking needed to determine roller speed should be accomplished prior to the actual test strip operations.

d. The participants should begin by predetermining the trial rolling zone, mix temperature, approximate compaction time, roller factors such as speed, amplitude, frequency, and test patterns. Note the term test patterns. The test strip should check several roller patterns to determine the optimum for that particular mix.



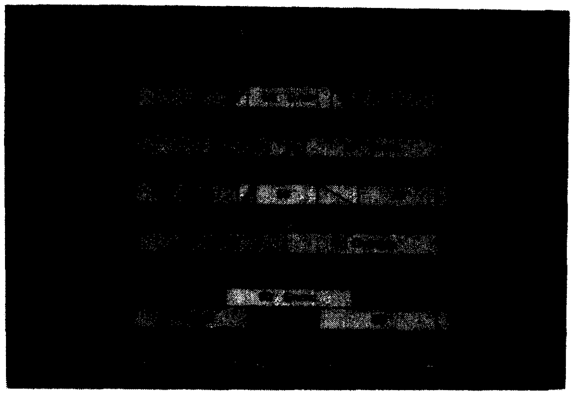
47. Test Strip Variables
During the test strip operation there are several variables that should be considered.

1. Roller speed should not exceed 3 mph.
2. The roller speed should be matched to production and coordinated with the frequency to produce the desired impacts per foot and desired finish of pavement.
3. The amplitude set at high, medium or low.
4. The roller lap should coordinate the roller width to the pavement width so as not to produce a overlap more than 6 inches while the roller is operated in vibratory mode.
5. The number of passes in the vibratory and static mode should be determined.
6. The rolling zone can be established depending upon the cooling rate of the mix and the compactive effort furnished by the roller.



48. Roller Pattern

In establishing a roller pattern, the roller stops on each successive pass should be staggered and not at one point. Stopping at one point could produce a bump that can not be removed during the final rolling operations.



49. Roller Overlap

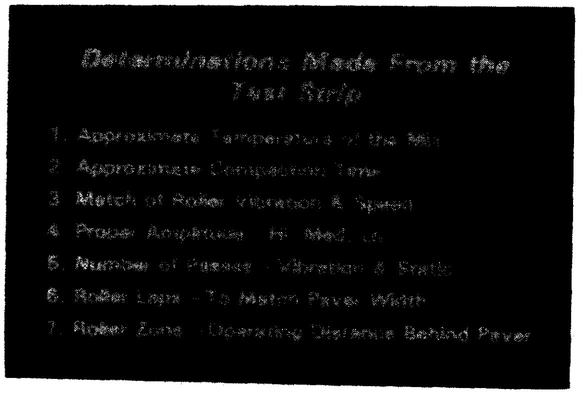
This slide illustrates several drum widths for paving a 12 foot lane. If a vibratory roller is being used, it is essential that the overlap be not more than 6 inches. Certain drum widths are well suited to a 12 foot pavement. However, notice the effects of the 60 inch drum as shown in the third drawing down.

On the third pass there will be a 2 to 3 foot overlap. If the roller is operated in the vibratory mode in this pass, the overlap portion will be decompacted and the target density may not be obtained. On projects that are experiencing problems obtaining the specified density, the first three things to check are:

a. Does the number and type of rollers appear adequate for the work involved?
b. Does the mix temperature provide adequate time for compaction for the project conditions?
c. If a vibratory roller is being used, is its width matched to the pavement width?

If one pass involves a substantial overlap, the chances are that all tests taken in the overlapped portion will fail. Also tests taken within 1 foot of the edge of pavement will probably fail the density requirements due to the lack of lateral support during compaction.

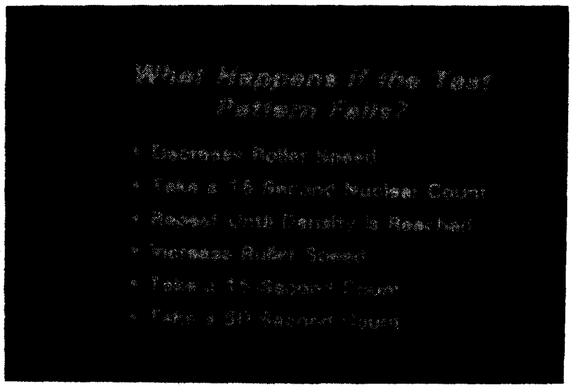
Again, when using vibratory rollers it is essential that the roller width be matched to the pavement width. If they are not matched, a modification should be made to the roller pattern. Again, note in the chart of the third drawing down shows the large overlap of the 60 inch roller. The last diagram gives a recommended alternate procedure. In this diagram the outside and inside portions are compacted in a vibratory mode. The center portion is then compacted in a static mode. The static compaction of the center strip may require more passes than the vibratory compaction on the outer two areas. This should be determined and made a part of the roller pattern.



50. Test Strip Determinations

At the end of the test strip operation, one should be able to make the following determinations.

1. The approximate temperature of the mix arriving on the project.
2. The approximate compaction time.
3. A combination of roller vibration and speed to produce the desired compaction and surface finish.
4. The proper amplitude.
5. The number of roller passes for optimum compaction both in the vibratory mode and static mode.
6. The proper roller lap and operations to match roller width with pavement width.
7. The approximate rolling zone.

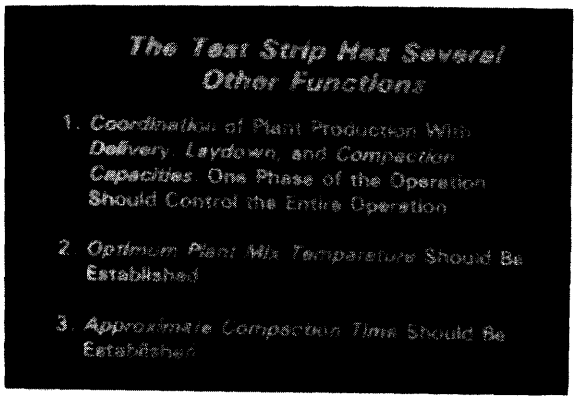


51. Test Strip Failures

While the nuclear gauge is essential for determining the optimum rolling pattern, the roadway density obtained during the test strip operations should be determined from cores taken from the pavement. If the test strip fails, several options can be taken.

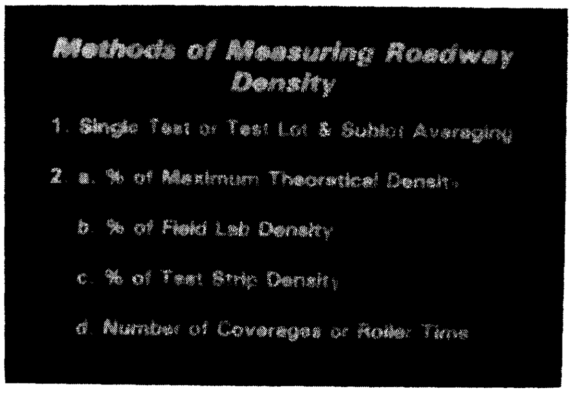
1. Additional rollers can be added to increase the compactive effort.
2. If possible the mix temperature can be increased to allow more compaction time.
3. The existing roller or rollers can be slowed down to increase the compactive effort.

In any case, appropriate changes deemed necessary should be made and another test strip run.



52. In addition to the previous functions of the test strip, it allows determination of the following:

1. It will identify which phase of the operation will control the speed of the overall operation.
2. The plant mix temperature, which should be set based on the temperature viscosity characteristics of the asphalt, will be determined.
3. The time available for compaction of the mix before it reaches 175 F will be able to be determined. This time will vary as previously discussed.



53. Roadway Density Methods
Depending on the specifications, a mat can be accepted from a single test or test lot and sublot averaging. Depending on the particular specification, there are several ways to specify a roadway density.

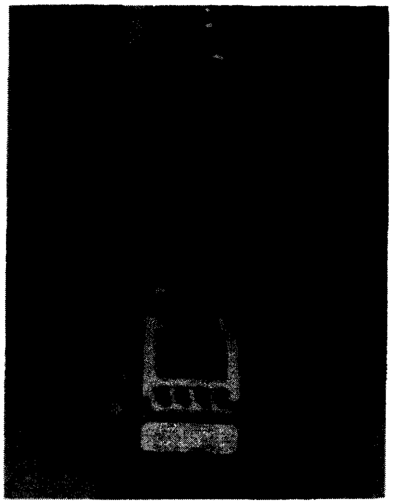
1. To specify a percentage of the maximum theoretical density, it is essential that we know which method was used for determining the specific gravity of the various material components and what the maximum theoretical density means in terms of true voids on the roadway. While the exact method for determining the true theoretical maximum density continues to be a subject of discussion, the Rice Method (AASHTO T209) is recommended for determining the maximum theoretical density. However, the Rice Method is based on the use of the dry aggregate. The procedure may need to be altered when testing drum mixes.

2. A percent of field lab density may be specified. This method is satisfactory provided it is correlated to the maximum theoretical density.

3. A percent of the test strip density may be required. Again, this method is satisfactory provided it is correlated to the theoretical maximum density in order to determine the true void range of the roadway mat.

4. A specified number of roller passes or roller time. Since this method alone is not based on the measurement of actual in-place densities, it is generally considered unacceptable.

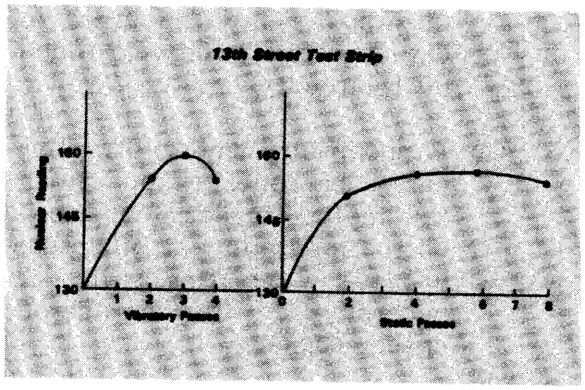
The important point of compaction is to obtain 6 to 8 pecent voids in the roadway after compaction and before it is open to traffic. A good density specification is one that assures a 6 to 8 percent void range in the compacted pavement.



54. Nuclear Gauge
A nuclear gauge is a necessity for determining optimum rolling patterns during a test strip operation. The nuclear gauge can also be used at any time during construction to determine the optimum rolling pattern of each particular roller and mix.

55. The nuclear gauge must be calibrated regularly with standard calibration blocks to assure its proper operation. Pavement cores should be taken to verify the nuclear densities. For lifts less

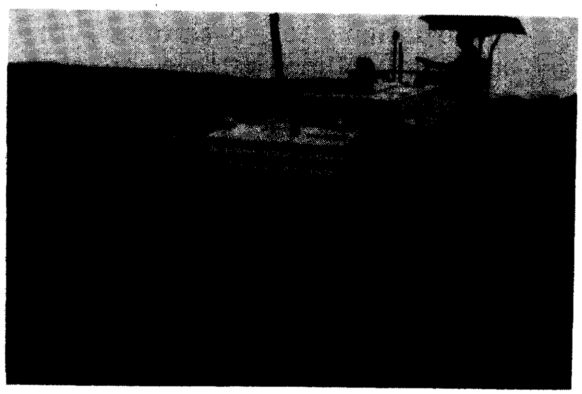
than 3" thick, nuclear readings or requirements must be adjusted to account for variation in the underlying surface density and for the difference between the new material density and the underlying density. Nuclear gauge manufacturers have developed information which can be used to make these adjustments for each of their gauge models.



56. Roller Pass Curve

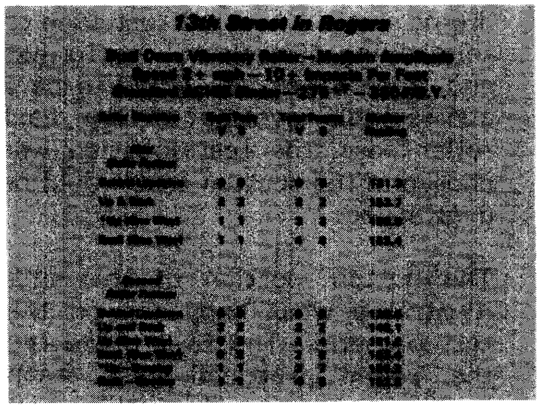
This is a plot of the roller passes versus nuclear reading for two test patterns. The vibratory mode was used in each pass on the plot on the left hand side. Note the sharp breaking curve. This illustrates the need for determining the number of vibratory passes needed in a roller pattern and strictly following that pattern. Remember that one additional vibratory pass can decompact the mix.

The plot on the right shows the effects of using the static mode for all passes. It produces a relatively flat rounding curve. The number of passes in the static mode is not nearly as critical as that in the vibratory mode. A few additional passes in the static mode will not decompact the mix nearly to the extent that one pass of the vibratory roller does.



57. Vibratory Roller on the Roadway

In the last few years the vibratory roller has probably become the most common piece of equipment used in the compaction of asphalt pavements. Many states used to specify a rolling train in which the breakdown was accomplished with steel wheel roller and intermediate rolling was accomplished with the rubber tired roller. As the state's specifications were changed from a rolling process to a density requirement, many contractors began using only the vibratory roller for compaction. This type roller was used on the following project.

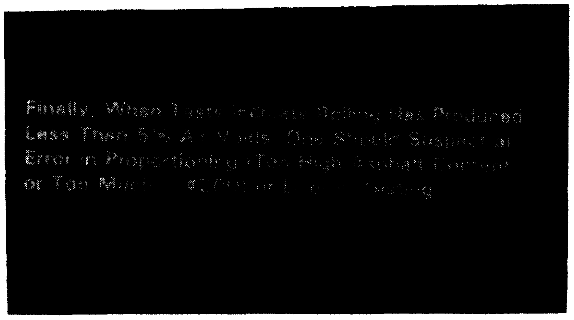


58. 13th Street

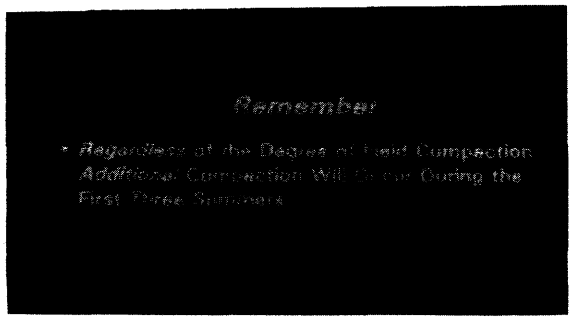
This is an example of a small test strip used in the laydown and compaction of a binder course. This test was run during actual construction and the contractor was operating a roller with one drum vibrating with a medium amplitude and the other drum static. The table shown on this slide shows the movement of the roller, the number of static and vibratory passes per pass of the roller, the accumulated total number of static and vibratory passes, and the nuclear reading. The results of the first roller pattern is illustrated in the top portion of this slide. The roller made one round trip up and back and a reading was taken. This resulted in two vibratory passes and two static passes over a given spot. This increased the reading to 153.7. The next reading was taken after the roller had gone up towards the paver. This involved one static and one vibratory pass for a total of three vibratory passes and three static passes. This increased the reading to 158.5. The final reading was taken after the roller returned giving one additional vibratory and static pass giving a total of four vibratory and four static passes, however, the reading had dropped back to 153.4. In this case the optimum rolling pattern consisted of three vibratory passes and three static passes.

The roller operator stated that normally he made one round trip with one drum vibrating and one static, and one round trip with both drums static. Another test strip on this rolling pattern was performed and since there was going to be a considerable overlap on the next roller pass, the test location was chosen in the section that would be overlapped.

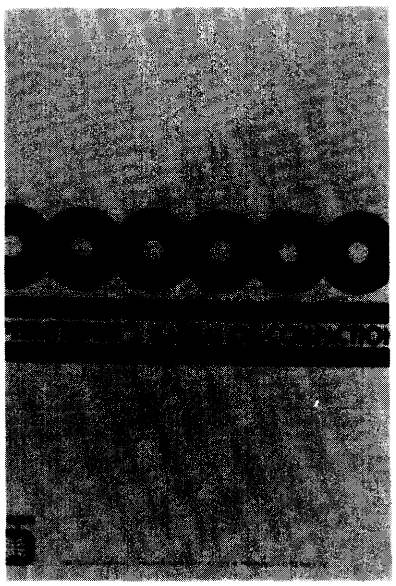
The bottom portion of this slide illustrates what happened on this test pattern. The first round trip the roller produced two static passes and two vibratory passes and increased the reading to 148.1. The next round trip in the static mode resulted in a total of four static passes and two vibratory passes, which increased the reading to 151.2. As the roller returned, it produced an additional two static passes giving a total of two vibratory passes and six static passes which increased the reading to 153.4. The roller then moved to compact the narrow strip overlapping the test section. The trip up was made in his normal compaction mode with one vibrator on and one static, this produced one vibratory and one static pass for a total of three vibratory passes and seven static passes. This increased the reading to 155.2. The return trip of the roller produced another vibratory and another static pass, which gave a total of four vibratory passes and eight static passes, but the reading was reduced to 152.2. Note that in both cases the maximum reading was produced on the third vibratory pass and that decompaction occurred on the fourth vibratory pass. Also note in the second test that a static pass produces very small increase in density compared to a vibratory pass.



59. Less Than 5% Voids
Generally when testing indicates rolling has produced less than 5% air voids, one should suspect an error in proportioning (too much asphalt content or filler) or an error in testing. One can anticipate rutting and/or flushing on a high performance pavement where the specified density is obtained in one or two passes. In these cases the mix should be redesigned.

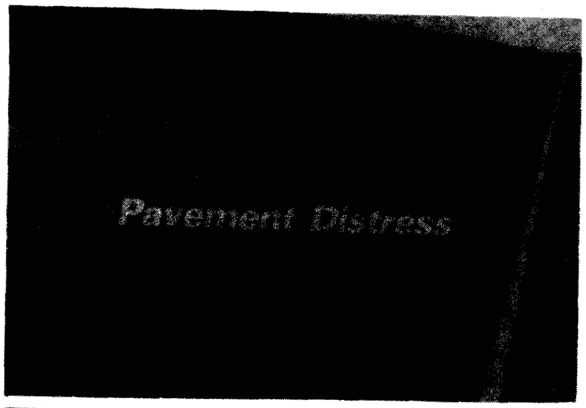


60. Regardless of the degree of compaction during construction, the mat will densify by consolidation and particle reorientation during the first several years. Most of the densification occurs during the first summer and the total amount depends on the stability of the mix.



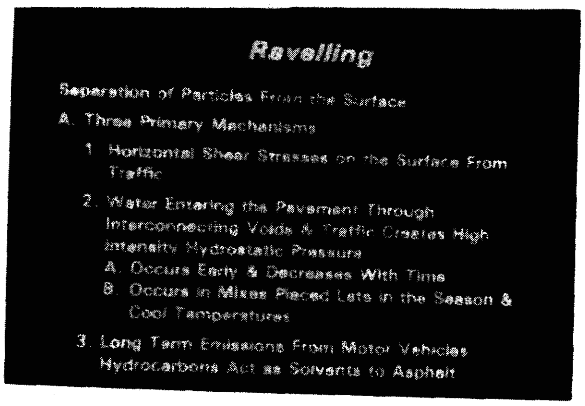
61. The NAPA Book, Superintendent's Manual on Compaction
The National Asphalt Pavement Association, Training Aid Series 12, "Superintendent's Manual on Compaction" is an excellent manual on compaction and should be made available to those associated with the production and compaction of asphalt mixtures.

62. This completes this section on compaction. This section discussed the purpose of and procedures for rolling the pavement and methods of determining and controlling pavement density.

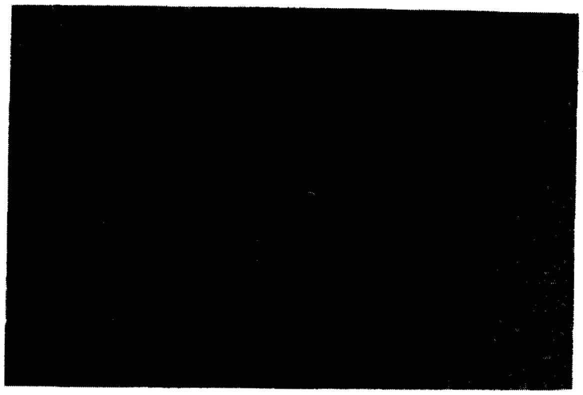


1. Pavement Distress
Having introduced several asphalt pavement distresses in the introduction section of this presentation and then discussing each phase of mix design and construction, we will now examine each distress in more detail to determine some possible causes and solutions.

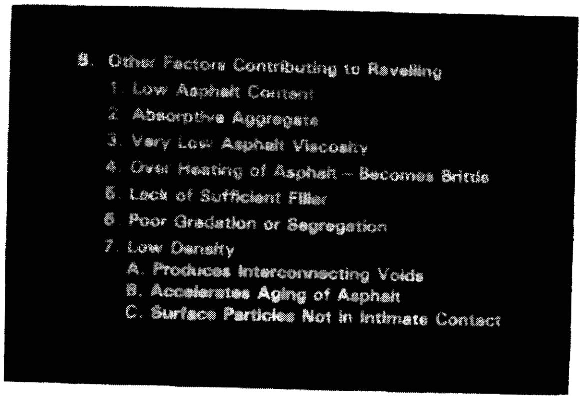
2. Ravelling: This is the separation of aggregate particles from the surface of an asphalt pavement.



3. The Primary Mechanisms for Ravelling are:
   1. The horizonal shear stresses on the surface of the pavement resulting from the action of the traffic.
   2. Water entering the pavement through interconnecting voids and high intensity hydrostatic pressure created by the traffic disbonds the surface particles. This type of ravelling usually occurs in mixes placed late in the season and in cool weather and occurs soon after construction and decreases with time.
   3. Long term emissions from motor vehicles can also cause raveling. The hydrocarbons from vehicle emissions act as solvents to asphalt.

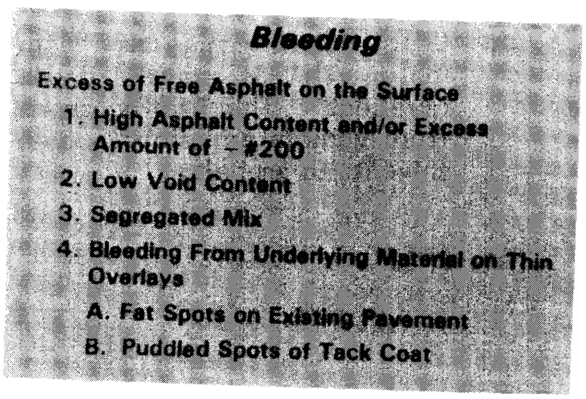


4. Severe ravelling can create a traffic hazard and will sometimes result in an increased rate of pavement deterioration.



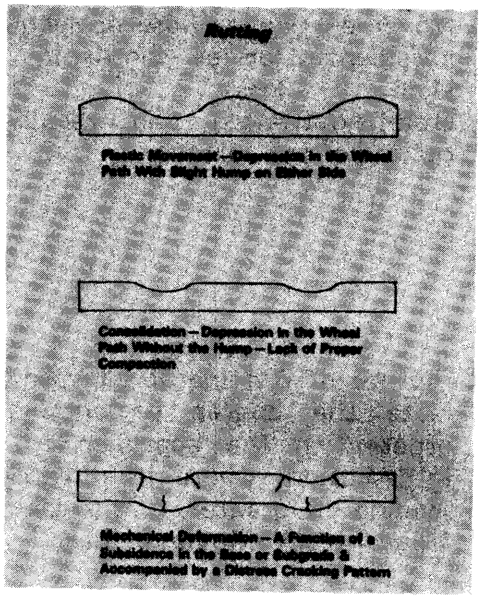
5. Other Factors Contributing to Ravelling:
   1. Low asphalt content which provides inadequate bond.
   2. Absorptive aggregates which reduce the effective asphalt content.
   3. Contamination of the asphalt resulting from unburned heavy fuel oils used in the mixing plant.
   4. Overheating causes the asphalt to become brittle.
   5. Lack of sufficient filler.
   6. Poor gradation - gap-graded mix with insufficient fines.
   7. Low density which produces interconnecting voids, accelerates aging of the asphalt, and does not put the surface particles in intimate contact with each other.

6. Bleeding: This is the presence of free asphalt on the surface of a pavement. It will result in extremely slippery pavement surfaces when wet.

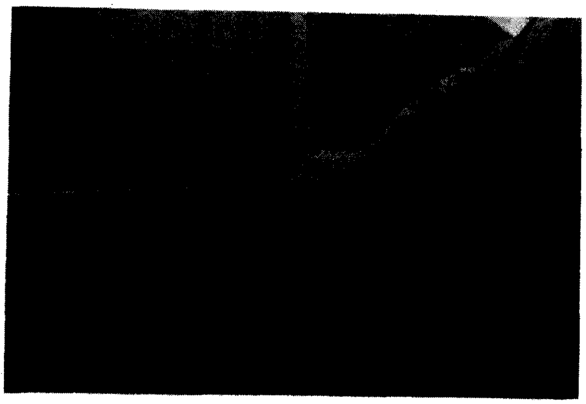


7. Bleeding results from mixes with high asphalt and/or mineral filler contents, low voids and segregated mixes. On thin overlays bleeding can result from "Fat Spots" on the existing pavement or from puddles of tack coat.

8. Rutting: This is the longidutinal deformation that develops in an asphalt pavement under the action of channelized loadings (traffic).



9. Three Types of Rutting:
   1. Plastic movement is a depression near the center of the applied load with slight humps on either side of the depression. This is generally caused by too low voids in the pavement mat that allows the asphalt to act as a lubricant rather than a binder.
   2. Consolidation is a depression near the center of the applied load without an accompanying hump on either side of the depression. This is generally caused by too high voids immediately after construction that allows the mat to consolidate in the wheel paths when subjected to traffic.
   3. Mechanical deformation is a result of a subsidence in the base, subbase, or subgrade, accompanied by a distress cracking pattern.

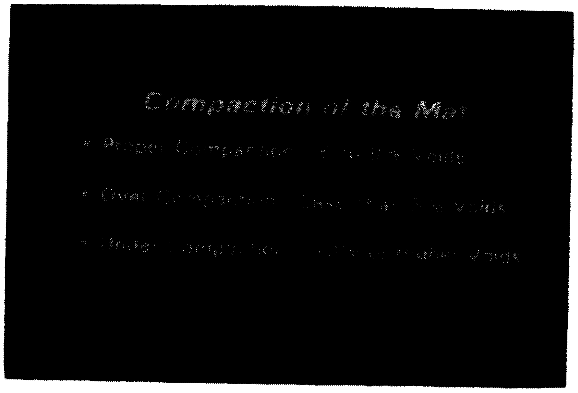


10. Picture of Rutting of Interstate Overlay. This is a plastic movement type rut experienced shortly after construction on an Interstate overlay project.
    This illustrates the amount of the movement. Mixes similar to this had been used successfully throughout this State on new construction and on low- volume facilities.

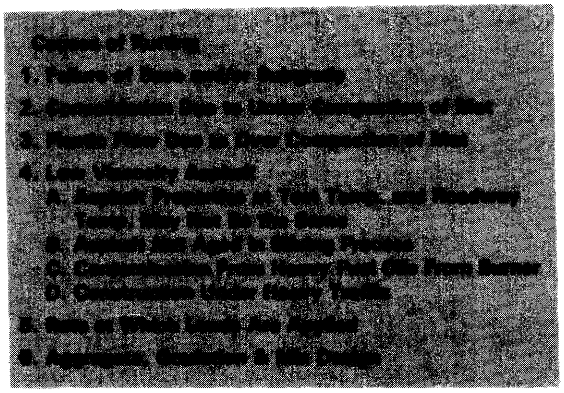
11. In this consolidation type rutting, the mat consolidates due to traffic, resulting in depressions in the wheel paths.

12. Movement due to base or subgrade subsidence, or as shown in this slide, loss of base stability/strength can result in rutting of the surface.

13. Picture of Rutting at Intersection. Note the degree of rutting is greater on the approach to the intersection where the rate of loading is greater. The same is true of truck climbing lanes.



14. Proper compaction of the mat during construction can reduce the rutting potential:
    1. 6% to 8% Voids: This degree of compaction, after construction rolling and before traffic, should result in 3% to 5% voids in the pavement after 3 summers of traffic.
    2. Less than 3% Voids: Such a pavement is over-densified. Actually a mix which can be compacted to this degree is poorly designed and should be redesigned. With this degree of density, the additional consolidation under traffic will probably result in rutting and/or bleeding.



3. More than 10% Voids: Such a pavement is underdensified. This degree of densification results from a lack of compactive effort or the mix becoming too cool before rolling and compaction is completed, or an improperly designed mix.

15. Causes of Rutting are:
    1. Further consolidation of the base, subbase, or subgrade.
    2. Undercompaction of the mat can cause consolidation rutting.
    3. Overcompaction of the mat can cause plastic movement.
    4. Low Viscosity Asphalts: The asphalt properties at test temperatures (77F and 140F) may not be the same as the inservice pavement temperatures. The asphalt may not be aged in the drum process as it is in the batch process. Unburned heavy fuel oils used for heating may coat the aggregate and contaminate the asphalt, thus reducing the viscosity. Construction under heavy traffic can result in rutting in the pavements before the asphalt cools sufficiently to contribute to the strength of the mix.
    5. Rate of Loading: The duration of a load affects rutting. Bituminous mixes are more resistant to short duration loads such as fast traffic conditions, and less resistant to long duration loads. This is the reason that rutting is most likely to be noticed at intersections and in climbing lanes than on the mainlanes of high speed facilities.
    6. Mix Design: The high stability mixes consisting of a uniformly graded rough surface textured chunky shaped aggregate with the proper asphalt content are more resistant to rutting.

Likewise, low stability mixes consisting of high natural sand content, low mineral filler, smooth rounded aggregate with low viscosity asphalt are less resistant to rutting.

Factors to Prevent Rutting

1. Mix Design With Uniformly Graded High Stability Aggregate
2. Not a High Natural Sand Content
3. Proper Asphalt Grade & Content
4. Proper Compaction & Air Void Content

16. Factors to Prevent Rutting:
    1. Mixes should incorporate a uniformly graded rough surface aggregate.
    2. Natural sand content should be limited to eliminate the ball-bearing effect.
    3. The proper asphalt grade and content should be selected for the climatic conditions and type highway.
    4. A proper air voids system in the compacted mat should be obtained.

SHOVING

Horizontal Displacement of an Asphalt Mixture

1. Low Stability Resulting in Plastic Flow
2. Slippage Under Horizontal Thrust

Causes

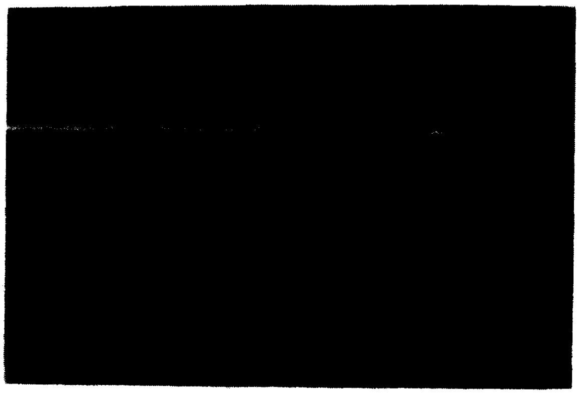
1. Oversanded Mix With Insufficient Filler and a Low Viscosity Asphalt
2. High Ambient Temperatures

17. Shoving is the horizontal displacement of an asphalt mixture.

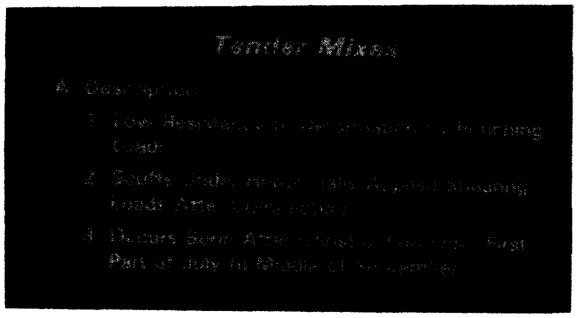
Shoving is usually associated with low stability mixes which under a horizontal thrust results in plastic flow. Also the mat can slip on the existing surface under a horizontal thrust. This slippage is sometimes caused by improper preparation of the existing surface. The existing surface can be either dirty or have excessive tack coat.

Most shoving can be traced to oversanded mixes with insufficient filler, a low viscosity asphalt, and/or low stability.

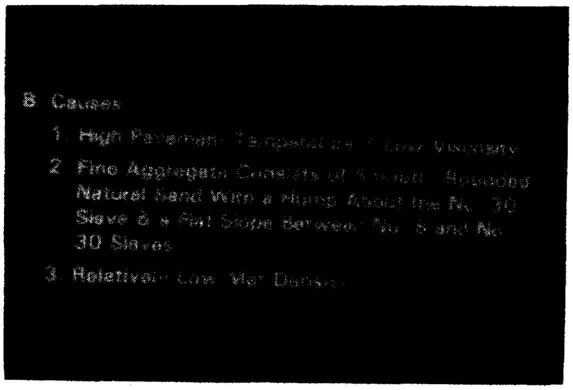
High ambient temperatures also play a role by softening the asphalt. Plastic flow indicates voids in the range of 3% or less.



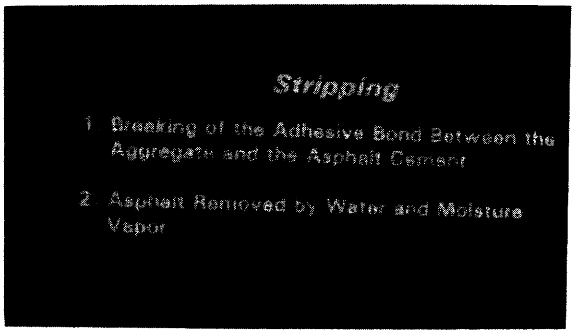
18. Picture of Shoving
Shoving can occur at the connection of an asphaltic pavement to a rigid pavement or to bridge approach slabs. Shoving also may occur in interchange and intersection areas where horizontal forces from vehicular traffic is increased.



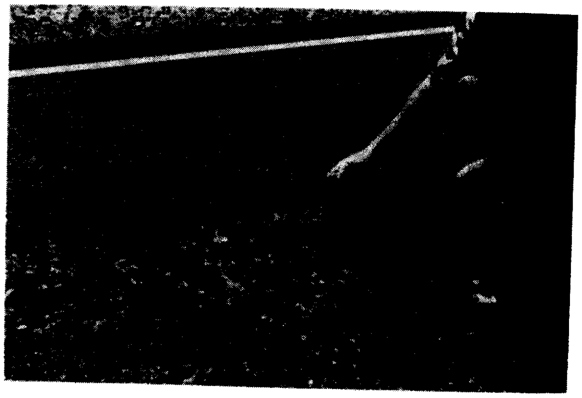
19. Tender Mixes: A tender mix has a very low resistance to deformation by a punching load and scuffs under a horizontally applied shearing load after compaction. Tender mixes are almost always reported soon after compaction during the period from the first of July to the middle of September.



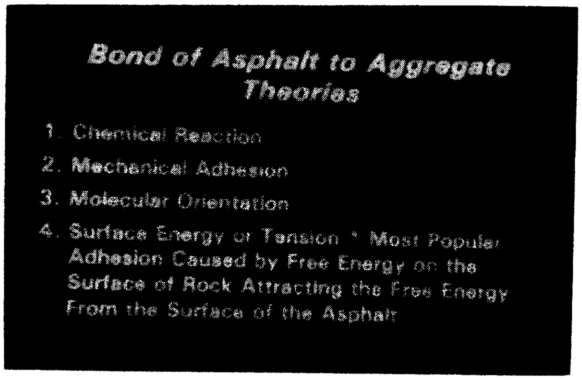
20. The Major Causes of Tender Mixes:
    1. High Temperatures and/or a Low Viscosity Asphalt: The high temperatures will soften the asphalt and require the mix to perform almost entirely on aggregate interlock. As the weather cools the asphalt is hardened and it performs as a binder adding strength to the mix. With time the asphalt ages, which also increases its viscosity.
    2. Aggregate type and gradation: Tender mixes are associated mostly with mixes using smooth, rounded, natural sand. It can sometimes be identified on a gradation chart by a hump about the #30 sieve and a flat slope between the #8 and #30 sieves.
    3. Low Density: Relatively low densities are associated with tender mixes.



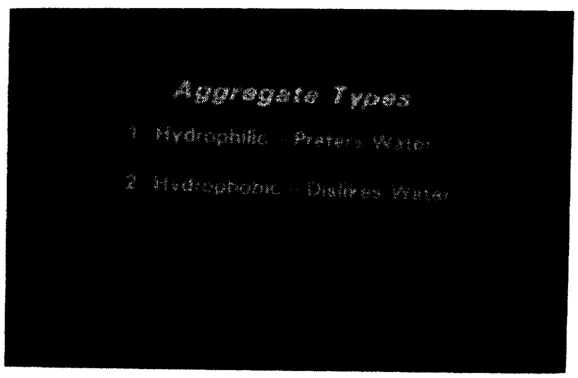
21. Stripping: Stripping is the breaking of the adhesive bond between the aggregate surface and the asphalt cement. Stripping occurs when water gets between the asphalt film and the aggregate surface. The asphalt is then displaced by the water or water vapor. Stripping may also result from the emulsification of the asphalt due to chemical inbalances.



22. Stripping does not start at the pavement surface and proceed down into the pavement structure, but normally starts in an interlayer of the pavement structure. Flushing or bleeding in the wheel paths may be an indication of stripping. Coring of these areas is the only way to determine its presence. Usually stripping can be detected from a visual inspection of the cores.

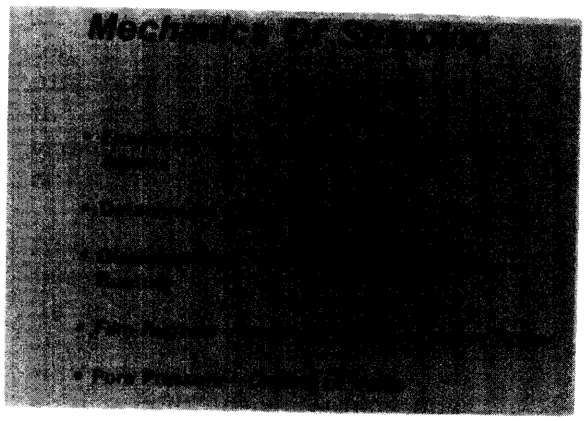


23. There are four theories as to why the asphalt bonds to the aggregate:
    1. A Chemical Reaction Theory
    2. A Mechanical Adhesion Theory
    3. A Molecular Orientation Theory
    4. A Surface Energy or Tension Theory. This is the most popular theory. It claims the adhesion is caused by the free energy on the surface of the aggregate attracting the free energy on the surface of the asphalt.

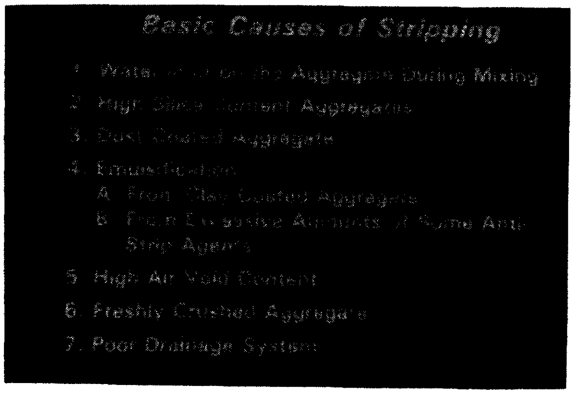


24. Aggregate Types:
    1. Hydrophilic or Water Loving Aggregates. These are the siliceous aggregates such as gravels. These aggregates normally have good friction qualities and are being used more because of the increased emphasis on skid resistance.

2. Hydrophobic Aggregates Dislike Water. These are the carbonate aggregates such as limestone. However, these aggregates usually have poor friction qualities in that they polish quickly under traffic. Therefore, caution should be exercised when using this type aggregate in a surface course.



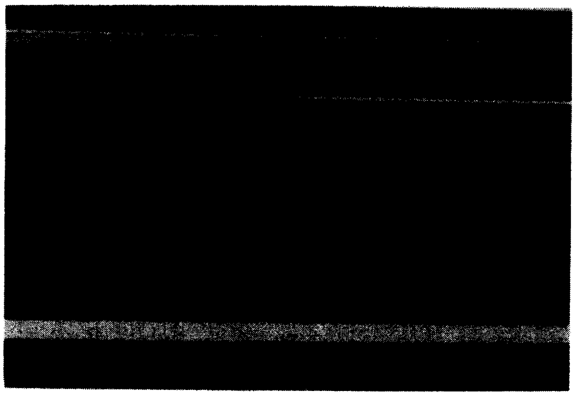
25. Basic Types of Stripping
    1. Emulsification results from the contact of water and certain chemical additives or certain mineral clays.
    2. Detachment is the separation of the asphalt from the aggregate surface by a thin layer of water with no obvious break in the asphalt film.
    3. Displacement is when the asphalt adhering to the aggregate surface is removed and replaced by water. In this case free water gets to the aggregate surface through a break in the asphalt coating.
    4. Film rupture is the rupture of the asphalt film on the aggregate particles. It is likely to occur under stress of traffic at the sharp edges and corners of the aggregate particles where the film is the thinnest.
    5. High pore pressure can contribute to stripping. In high void asphalt mixtures, water may circulate freely through the interconnecting voids. Then as densification under traffic occurs, the voids are reduced and the passages between the voids are closed, trapping the water. As the traffic and mat densification increase, the trapped water is subjected to pressure and stripping can occur.



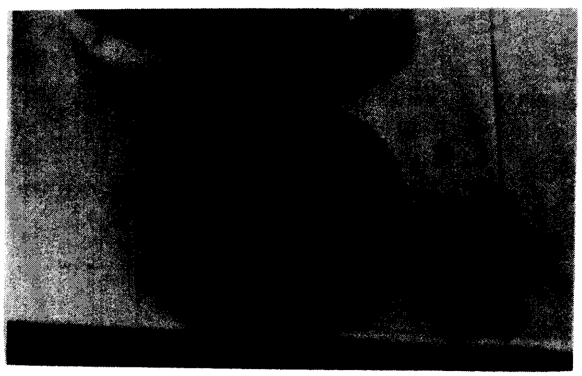
26. The Cause of Stripping: There is only one cause of stripping and that is water getting between an asphalt film and an aggregate surface and replacing the asphalt as the aggregate's coating. However, the following are several ways the water can get to the aggregate surface.

1. Water in or on the aggregate: Aggregate that absorbs water or attracts water to its surface will strip easily if not properly dried. Aggregate temperatures in excess of 212°F are needed to properly remove the moisture from the aggregate.
2. Aggregate type: Few, if any, aggregates completely resist the action of water under all conditions of use. However, it is generally believed that aggregates with high silica contents are more prone to strip than aggregates with low or no silica content.
3. Dust-Coated aggregate: Asphalt does not adhere to aggregate particles, especially coarse aggregates, that are coated with a film of dust. In the presence of water the particles strip readily because the dust creates pinholes in the asphalt film and allows water access to the aggregate surface.
4. Spontaneous emulsification: When under traffic the asphalt in mixtures can react with free water to form an emulsion. This results in a water droplet in the asphalt film. Some anti-strip additives, especially in excessive amounts, can act as emulsifiers. Clays from coated aggregate combined with water, pavement heat, and traffic pressure can also emulsify the asphalt.

5. High air voids: A pavement with high voids results in passages that allow the movement of water and water vapor through the mixture. Therefore, asphalt pavements with excessive air voids are more likely to strip, especially if a properly operating drainage system is not provided.
6. Stockpile age: During the crushing operation, the orientation of the surface molecules is disturbed and the freshly crushed aggregate may have poor asphalt stripping resistance. Stockpiling the aggregate for a week or more allows time for the surface molecules to reorient and may improve the stripping resistance.
7. Free water: Usually free water exists from improper drainage or where free drainage is not provided such as a high ground water table or pavements built in trench sections. In some cases, especially in overlays, water can be collected and trapped in the pavement during construction.

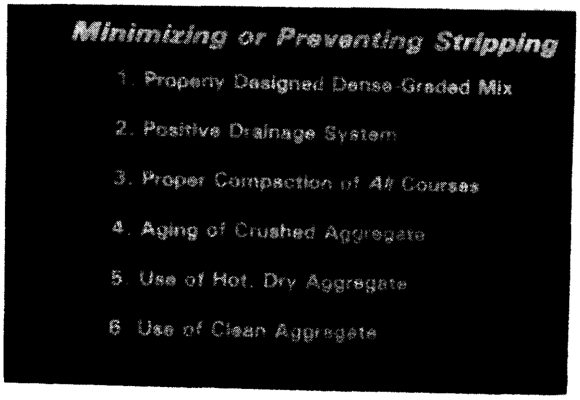


27. Stripping is difficult to identify by visually examining the pavement surface. Sometimes it is accompanied by spots of bleeding asphalt on the pavement surface, as shown here. A core was taken from this and several other locations to determine the presence and degree of stripping.

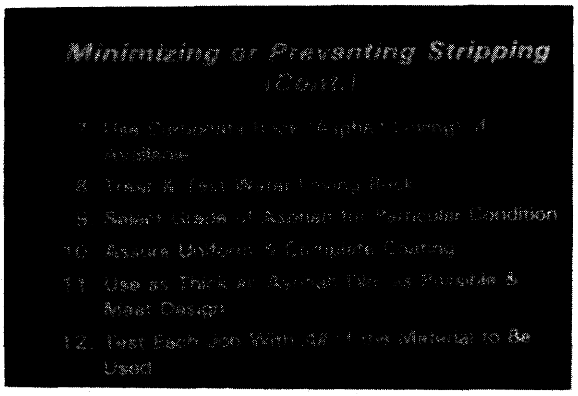


28. Picture of Core and Signs of Stripping. This core indicated stripping as can be seen by the bright clean aggregate particles and its low tensile strength.

29. Picture of cores with signs of stripping. Cores from pavements with severe stripping are nearly impossible to obtain because they fall apart during removal. These cores show various levels of stripping. Sometimes stripping in a layer may be indicated by what looks like an excess of asphalt because the stripped asphalt concentrates in one area.



30. Steps to Minimize or Prevent Stripping:
    1. For new pavements, use a well designed, dense graded, well compacted, asphalt concrete.
    2. Provide a positive drainage system for the pavement structure. If free water is removed quickly or kept away from the asphalt-aggregate mixture, stripping is less likely to occur.
    3. Make sure that all courses in the pavement are thoroughly and properly compacted. In most cases, a compacted mix should contain 6% to 8% voids.
    4. Do not use freshly crushed aggregate with poor stripping resistance. Aggregate should be stockpiled after crushing for a week or more before use.
    5. Use hot, dry aggregate. If the aggregate is surface dry, so that no moisture exists between it and the asphalt film, stripping is less likely to occur.
    6. Use clean aggregate: Even if the asphalt completely coats a dust coated aggregate, the dust coating prevents the asphalt from sticking to the aggregate surface. If the coating is clay, the clay may act as an emulsifier.



31. 7. Do not use highly stripping prone aggregate if a choice is available. Use an accepted water sensitivity test, such as the Immersion Compression Test (AASHTO T165 and T167) and the same asphalt chosen for the project to determine which aggregate is best for the project.

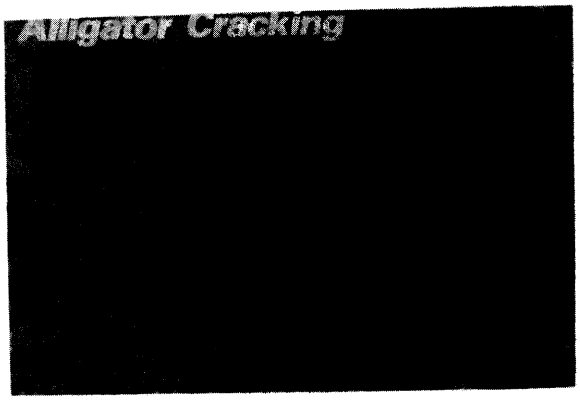
8. When using hydrophilic aggregate, add hydrated lime in the proper amounts as determined by laboratory mix design and water sensitivity tests. There are several research projects presently underway to determine satisfactory methods of adding hydrated lime in the various types of production operations.

Several ways have been tried to treat the aggregate,

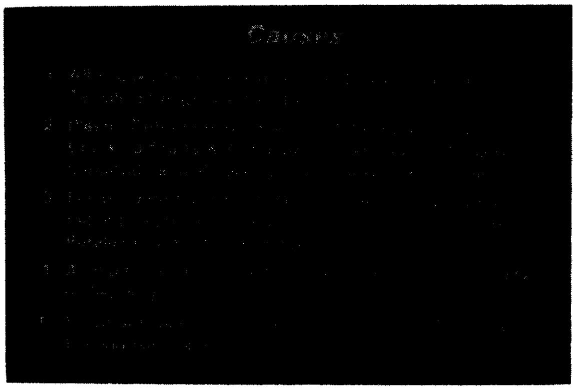
- treat the aggregate with a hydrated lime slurry.
- add the lime to the aggregate during production.
- add the lime to the cold feed belt in a drum mixer process.
- add the lime to the pug-mill in the batch mixer process.
- add the lime to the asphalt.

If a chemical anti-strip additive is used, it should be proven effective with the materials in the mixture. Some chemical anti-strip agents are not compatible with some asphalts or aggregates. A thorough laboratory investigation is essential to detemine which agents are compatible with a particular mixture and the quantity to be added. All chemical anti-strip additives are not heat stable after about 96 hours. Therefore, in-line blending in the asphalt line just prior to adding the asphalt to the aggregate at the hot mix plant is the preferred method of adding an anti-strip additive.

9. Select a grade of asphalt that at the mixing temperature will properly coat the aggregate.
10. Make sure the aggregate particles are completely and uniformly coated with asphalt.
11. Design the mix to use as thick an asphalt film as possible and still meet all of the design criteria. This may require several aggregate gradation trials to determine optimum asphalt content. A thick and uniform film of asphalt makes it difficult for the water to find its way to the aggregate surface.
12. Mix design procedures should provide for all mixes to be designed using all of the actual materials to be used on the project and should include a water susceptibility test.

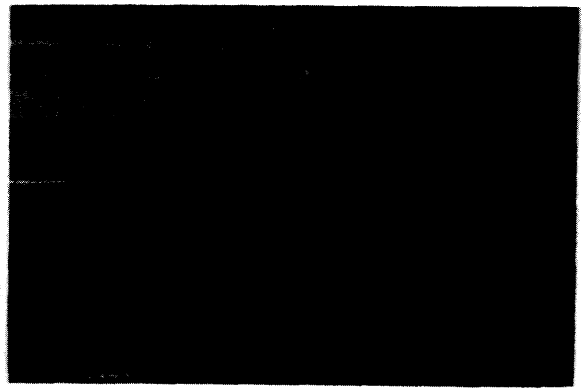


32. Cracking of an asphalt pavement is considered a normal failure mechanism. Premature cracking may indicate a mix design problem or a construction problem.

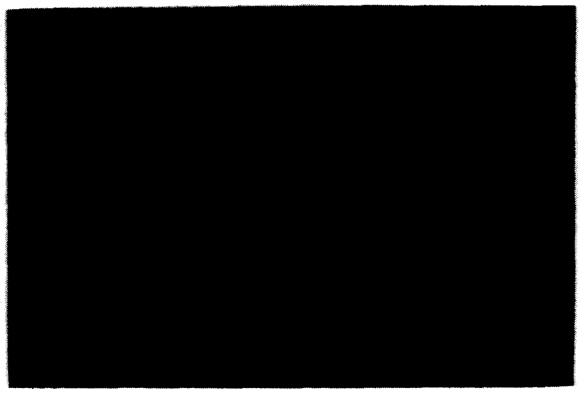


33. Causes and Development of Cracks:
    1. All cracks result from a tensile stress greater than the tensile strength of the mixture.
    2. Plastic deformation is when the surface deflects and remains. The cracking starts at the point of maximum bending and continues under repeated loading. The longitudinal and parallel cracks eventually connect to form the cracking pattern.
    3. Elastic deformation is when the surface deflects and recovers. The initial crack starts with a longitudinal crack in the wheel path. This is followed by an additional parallel crack. Again the cracking pattern eventually follows.
    4. Use of a high viscosity asphalt will result in a less resilient mix that is less able to accommodate bending.
    5. Extreme changes in temperature experienced in a pavement may cause it to crack transversly resulting in thermal cracks.

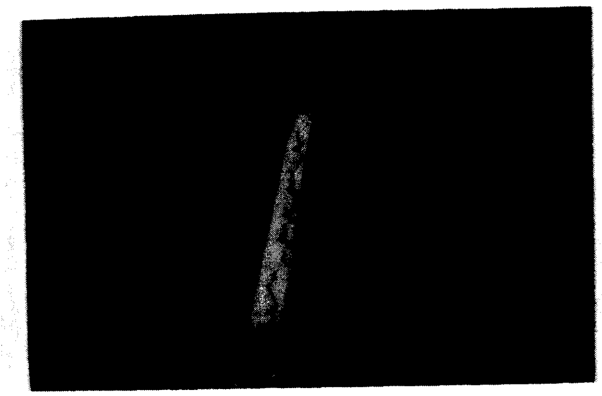
34. Picture of Block Cracking: Block cracking is usually rectangular in shape. Block cracking is not load associated.



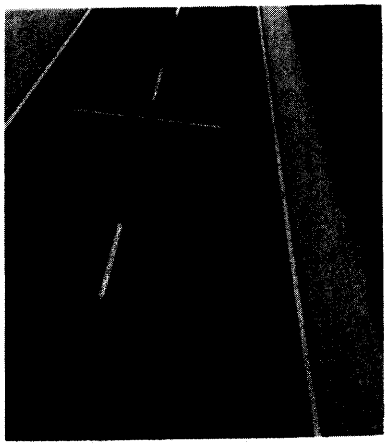
35. They are caused by the shrinkage of the asphalt concrete and the stress/strain cycle resulting from the daily temperature cycle. Block cracking normally begins with a transverse crack. While they are not load associated, loads can increase the severity of the cracks.



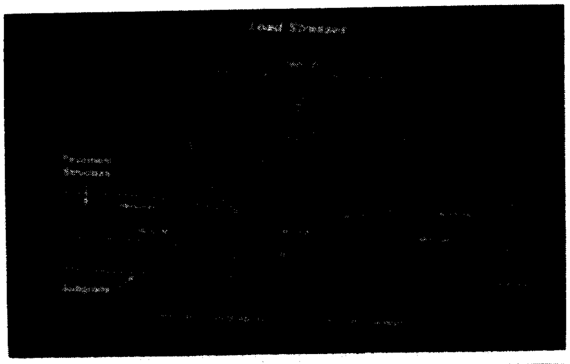
36. Picture of Longitudinal Crack at a joint: This is common in cold, poorly compacted joints.



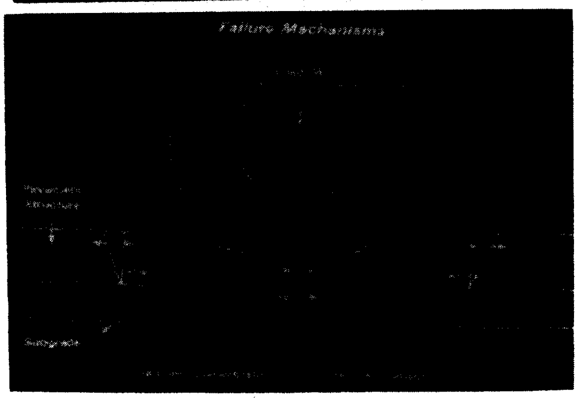
37. When longitudinal cracks such as this develop, it allows water to enter the pavement which increases the rate of deterioration.



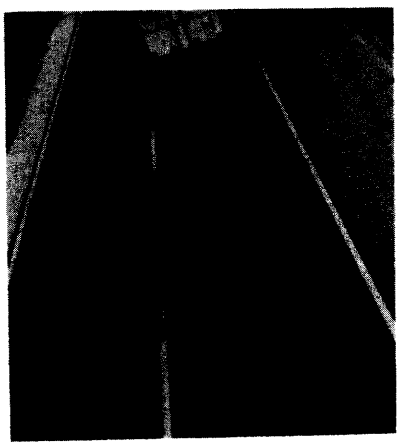
38. Alligator - Fatigue - or Pattern Cracking: This is a series of interconnecting cracks caused by fatigue failure of the asphalt concrete or base or subgrade. It is a load associated crack which starts at the bottom where the stress is greatest. This type cracking again starts as one or two longitudinal cracks in the wheel path and progresses to the alligator cracking pattern.



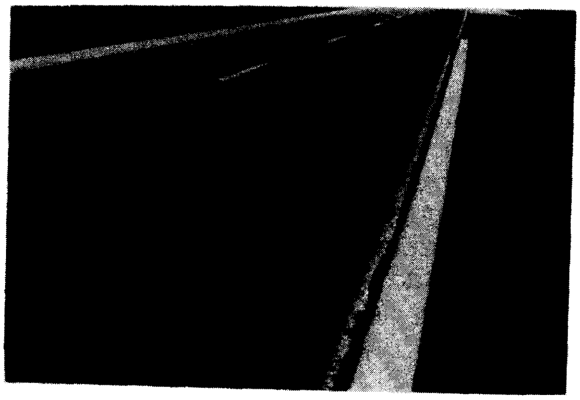
39. Picture of Wheel on Pavement:
As a wheel load moves over a spot in a pavement it creates a series of stresses that vary between tension and compression.



40. Picture of Wheel on Pavement and Developing Crack:
As the number of wheel loads accumulate, this stress/strain reversal will result in fatigue failure and a crack will develop.



41. Picture of Alligator Cracking in Wheel Path:
A structurally well designed pavement will generally show this fatigue cracking in the inner wheel path in the lane that carries the most traffic toward the end of its service life. This is because the combination of load and environmental induced stresses peak at this location.



42. Alligator Cracking in Wheel Path: Cracking will also develop where a weak spot in the underlying layer exists. This could be from inadequate compaction during construction or later water infiltration.

43. Cracking in wheel path with part of the surface course removed. If not overlayed or sealed in some way, the cracks allow water to enter the pavement and the base or subgrade. The presence of water in these layers of the pavement structure weakens them. Since this is a load associated distress crack, the presence of water accelerates the deterioration of the pavement.

44. Picture of pumping of flexible pavement: Flexible pavements can become sufficiently rigid over time to produce pumping, as shown here.

45. This completes this section on asphalt pavement distresses and the overall presentation. In summary, it has shown how the major phases in bituminous mix design and construction are interrelated. It has shown also how a change in one element can cause a problem in other elements which may seem unrelated, and could lead to premature pavement distress.

REFERENCE MATERIAL

Chapter 1 - Bituminous Paving Introduction

Highway Pavement Distress Identification Manual, U.S.D.O.T./FHWA March 1979

Principles of Consruction of Quality Hot-Mix Asphalt Pavements, MS-22, The Asphalt Institute

Chapter 2 - Materials and Mix Design

A Brief Introduction to Asphalt and Some of Its Uses, MS-5, The Asphalt Institute

Aggregate Gradation for Highways, Bureau of Public Roads, 1962

Mix Design Methods for Asphaltic Concrete, MS-2, The Asphalt Institute

Influence of Viscosity of Asphalt Cements on Compaction of Paving Mixtures in the Field, Norman W. McLeod, Presented at the 45th Meeting of the Highway Research Board, 1966

Design of Hot Asphalt Mixtures, ES-3, The Asphalt Institute

Paving Asphalt, ES-8, The Asphalt Institute

Selection of Local Aggregates for Hot Asphalt Mixtures, ES-7, The Asphalt Institute

Chapter 3 - Hot-Mix Plants

Asphalt Plant Manual, MS-3, The Asphalt Institute

Bituminous Construction Handbook, Barber Greene Company

Stockpiling and Cold Feed for Quality, IS-69, National Asphalt Pavement Association

Drum Mixing Principles, Barber Greene Company

Thermodrum Drum Mixing Plants, Barber Greene Company

Chapter 4 - Placing Hot-Mix

Asphalt Paving Manual, MS-8, The Asphalt Institute

Placing Hot-Mix, Training-Aid Series 4, National Asphalt Pavement Association/The Asphalt Institute

Pavement Smoothness, National Asphalt Pavement Association

Truck Driving Techniques, National Asphalt Pavement Association

Paver Operation for Quality, IS-59, National Asphalt Pavement Association

Principles of the Asphalt Finisher, Barber Greene Company

Chapter 5 - Compaction

Superintendent's Manual on Compaction, Training-Aid Series 12, National Asphalt Pavement Association

Factors Affecting Compaction, ES-9, The Asphalt Institute

Vibratory Compaction of Asphalt Paving Mixtures, ES-2, The Asphalt Institute

Rolling and Compaction of Asphalt Pavements, Instructor's Manual, National Asphalt Pavement Association/The Asphalt Institute

Roller Operation for Quality, National Asphalt Pavement Association

Chapter 6 - Asphalt Pavement Performance

Cause and Prevention of Stripping of Asphalt Pavements, ES-10, The Asphalt Institute

Tender Mixes; The Causes and The Cures, IS-168, The Asphalt Institute

Segregation - Causes and Cures, Technical Bulletin #T-101, 1979, J. Don Brock, PhD., P.E., Astec Industries, Incorporated

Problems with Asphalt Pavement Performance, Presented at the Conference on Asphalt: It's Effects on Pavement Performance, Vaughn Marker, The Asphalt Institute

Asphalt Overlays for Highway and Street Rehabilitation, MS-17, The Asphalt Institute

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HHO-33/10-84(1.5M)EW
HHI-23/R2-85(1,5)EW
HRT-10/R7-89(2M)EW