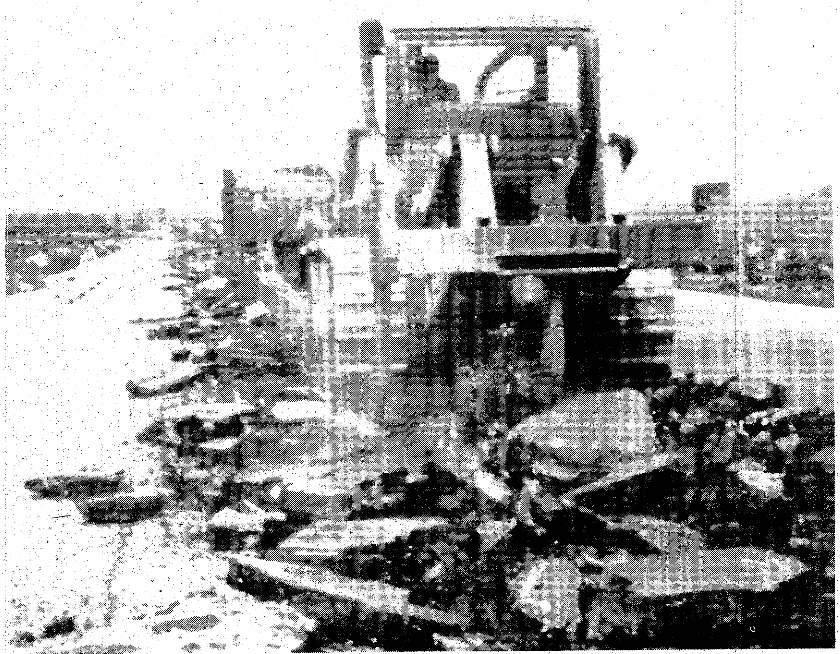
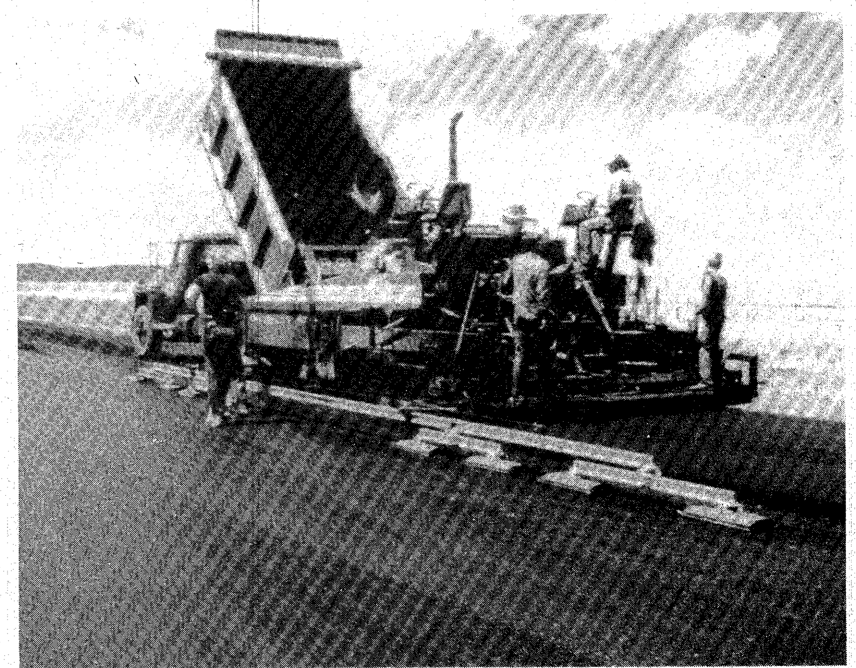
U.S. Department
of Transportation

**Federal Highway
Administration**

Asphalt Concrete Recycling





FHWA-DP-88-001

March 1988

ASPHALT CONCRETE RECYCLING

Federal Highway Administration
Office of Highway Operations
Demonstration Projects Division
and
Pavement Division
March 1988

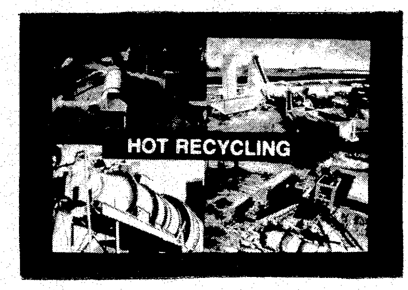
Preface

The information in this training booklet was obtained from the report "Pavement Recycling Guidelines for Local Governments - Reference Manual", FHWA-TS-87-230 and visual aids which were prepared under a Rural Technical Assistance Program (RTAP) contract.

The intent of this booklet is to serve as a participant's manual for the one-hour training sessions on Hot-Mix Asphalt Recycling and Cold-Mix Asphalt Recycling. More detailed information on these topics as well as on the other types of pavement recycling is contained in FHWA-TS-87-230. The report plus additional training materials are available at RTAP Centers.

Notice

HOT-MIX ASPHALT RECYCLING



1. Hot-mix asphalt recycling is a process in which reclaimed materials are combined with new ones in a central plant to produce hot asphalt concrete mixtures. The reclaimed materials can be either reclaimed asphalt pavement (RAP) or reclaimed aggregate materials (RAM). The new materials may include aggregates, asphalt and modifiers.

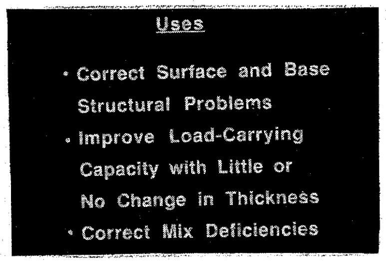
   With today's equipment, all hot-mix producers can recycle using existing plants with relatively inexpensive modifications. Plants specifically designed for recycling are also available.

   Hot-mix asphalt recycling, although relatively new, is a proven technology. It is less experimental than cold-mix asphalt recycling. It is an effective way to restore an asphalt pavement while conserving natural resources, such as, asphalt, aggregates and energy. It can also result in cost savings. Hot-mix asphalt recycling can fulfill these goals while meeting the following requirements:

   a. Produce stable mixes that are equivalent to conventional mixes,

   b. Achieve production levels similar to conventional mixes, and

   c. Meet air quality requirements.

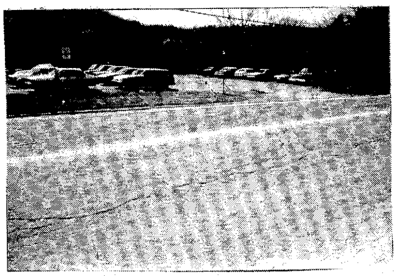


2. Hot-mix asphalt recycling has other uses and benefits:

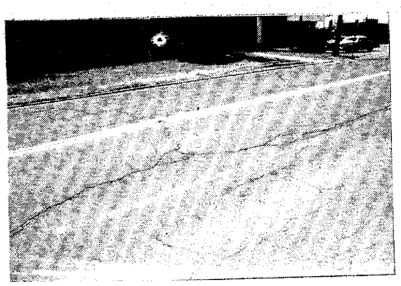
   a. Surface and base structural problems can be corrected,

   b. Structural improvements can be obtained with little or no change in thickness, such as when RAM is recycled, and

   c. Existing mix problems can be corrected.

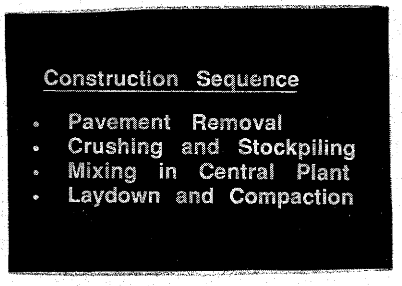


3. This city street exhibits alligator cracking. If left untreated, the cracking will become more severe, reducing the riding quality of the pavement.



4. A common repair would be to overlay the street with a new layer of asphalt concrete. There is, however, a limit to the number of overlays that can be placed. Too many can cause cross slope, drainage and clearance problems.

   A second alternative is to tear up the old pavement and replace it with new hot-mix. However, this could result in the wasting of the existing materials which, with proper treatment, could be reused to produce a strong and smooth riding surface.



5. Hot-mix asphalt recycling involves four basic construction activities:

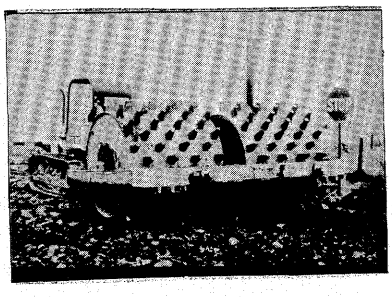
   a. Pavement removal,

   b. Crushing and stockpiling,

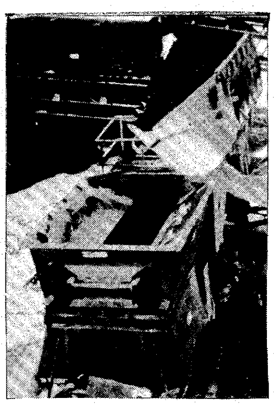
   c. Mixing in a hot-mix plant, and

   d. Laydown and compaction.

6. One method of removing and sizing the RAP is to break up the pavement using rippers, grid rollers, earthmoving equipment, or scarifiers. The RAP is then loaded into trucks and hauled to a hot-mix plant where it is crushed.

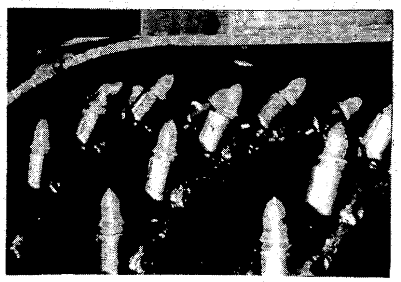


7. Ripping and crushing is feasible only when the full depth of the asphalt pavement is being removed, since the depth of cut cannot be controlled. Its main advantage is that standard construction equipment can be used.



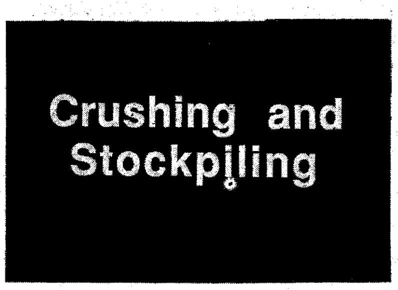
8. The chief disadvantage is that a separate crushing operation is always needed. There is also the potential for contaminating the RAP with underlying roadbed material.

9. An alternative method is to remove and size the RAP in-place using cold milling machines. This equipment offers good control of maximum particle size, has high productivity and reduces the need for further crushing. Cold milling machines are well suited to partial depth removal.



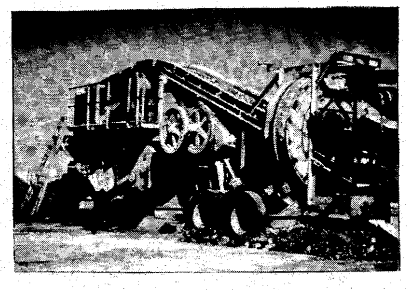
10. Attention is required when cold milling to ensure that the RAP is reduced to the proper size. Setting the cutting drum in the down-cutting mode generally gives the best results.

    Cold milling may increase the amount of fines in the mix due to aggregate degradation. This fact must be taken into consideration during the mix design, particularly if the design was based on core samples.

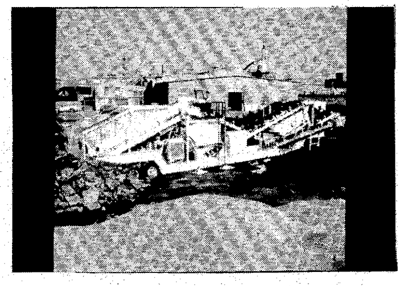


11. The amount of processing needed for the RAP prior to mixing depends largely on the removal method. RAP produced by ripping will have to be crushed and screened to reduce the maximum particle size to acceptable limits.

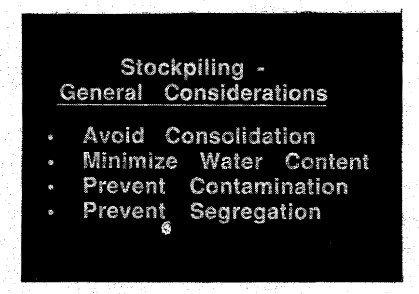
12. Cold milled RAP should also be screened prior to mixing to remove any oversized particles. The Asphalt Institute recommends that at least 95 percent of the RAP pass a 2 inch sieve.



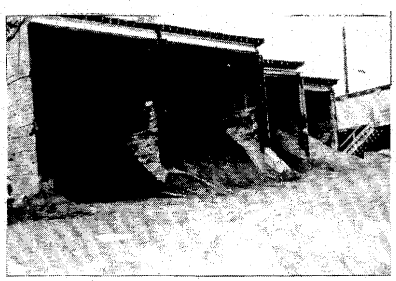
13. For large sized RAP, a primary jaw crusher of sufficient size, 30 x 42 inch minimum, is required. For smaller RAP, crushing may be accomplished with a secondary crusher. RAP from thick asphalt pavements usually requires both.



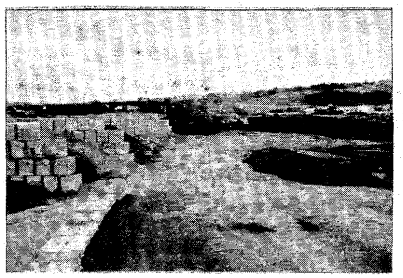
14. Specially designed impact-type crushers have been developed for handling RAP. They are capable of breaking the oversized material without generating excessive fines or significantly altering the aggregate gradation in the RAP. These newer machines also reduce problems with sticking at high ambient temperatures.



15. Stockpiling of RAP can cause problems of consolidation, moisture retention, contamination and segregation. To avoid consolidation, stockpile heights should be limited to 10 feet so that the weight of the pile will not compact the material at the base. For the same reason, equipment should be kept off of the stockpile.



16. RAP has a tendency to absorb moisture because of its higher content of fine particles. Since the heat required to evaporate this moisture comes from the super-heated virgin aggregate, higher moisture contents will result in lower production rates or in less RAP being used. Protective coverings can be effective. Drainage should be provided to prevent water from accumulating under the stockpile.

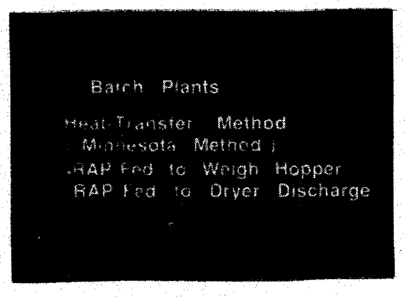


17. RAM and RAP should be processed separately to prevent contamination. The RAP should be further separated based on the degree of cleanliness, how it was produced and on differences in asphalt content and gradation. This becomes especially important as the percentage of RAP in the mix is increased. Stockpiles should be built on solid surfaces to reduce the potential for contamination.

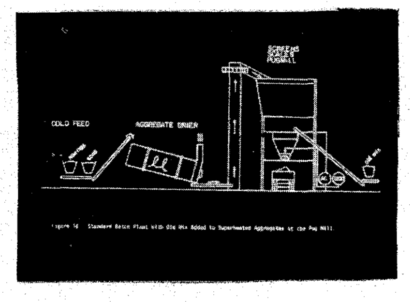
18. Segregation can affect pavement quality by reducing uniformity. In a stockpile, the larger pieces tend to roll to the outside. This can be minimized by varying the stockpile heights and by overlapping piles.

19. Where possible, the removal, crushing, and mixing operations should be coordinated to minimize stockpile size and reduce the problems caused by large piles.

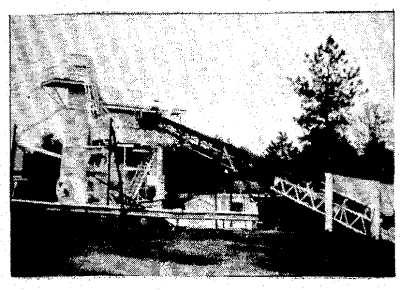
20. Conventional hot-mix plants have been successfully modified to produce recycled mixes. The objective is to heat and dry the RAP without exposing it to the flame or hot gases in the dryer. Direct exposure to the flame will burn the old asphalt causing excessive smoke and additional asphalt hardening.



21. Unsuccessful attempts have been made to add the RAP to the virgin aggregate prior to heating. However, the only successful technique for batch plant recycling is the heat-transfer method. It is widely used and can be installed on any batch plant.

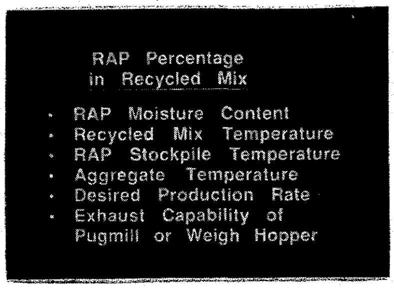


22. In the heat transfer method, the new aggregate or RAM is processed in the normal manner. The aggregate is conveyed from the cold feed bins into the dryer where it is heated to temperatures as high as 600° F. From the dryer, the super-heated aggregate is carried up the hot elevator to the top of the batch plant tower. The hot aggregate passes over the screen deck and is divided by size into the hot storage bins. The material is then weighed out into the weigh hopper.



23. The RAP bypasses the dryer, the hot elevator and the screens, entering the weigh hopper directly from a separate conveyor or via an adjacent bin. The RAP should be fed last into the weigh hopper to keep it from sticking to the hopper.

The transfer of heat from the virgin aggregate to the RAP starts in the weigh hopper, but most occurs in the pugmill. Temperature equilibrium in the mix may not occur until after it leaves the pugmill.



24. The amount of RAP which can be used in the heat transfer process is determined by:

a. Moisture content of the RAP,

b. Required temperature of the completed mix,

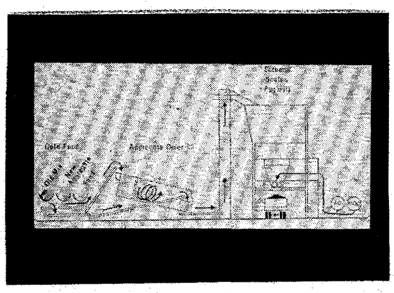
c. Stockpile temperature of the RAP,

d. Temperature of the heated aggregate,

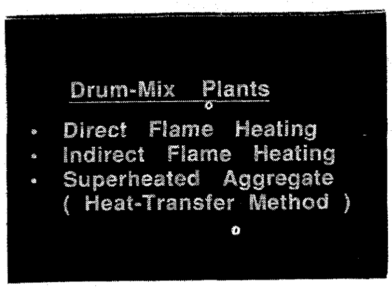
e. Desired production rate, and

f. Physical capacity of the pugmill or weigh hopper.

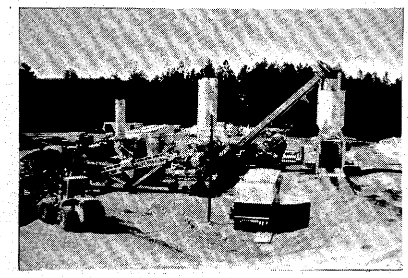
Batch plants have recycled up to 50 percent RAP if the moisture content was low. A more practical upper limit is 30 to 35 percent, with 10 to 20 percent being typical.



25. An alternative batch plant method introduces the RAP at the dryer discharge. The RAP travels with the super-heated virgin aggregate up the hot elevator to the screens. This approach is not commonly used since it is only suitable for small percentages of RAP.



26. The drum mixer plant is also readily adaptable to recycling. A number of equipment configurations have been developed using direct flame heating, indirect flame heating and the heat-transfer method.



27. Drum mixer plants have several advantages over batch plants when used for recycling:

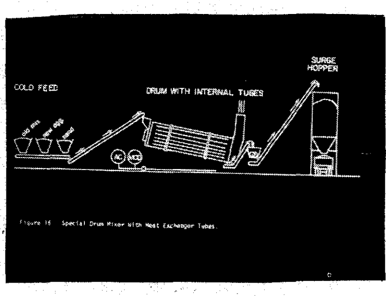
    a. Higher percentages of RAP can be recycled,

    b. There is little effect on plant production rates, and

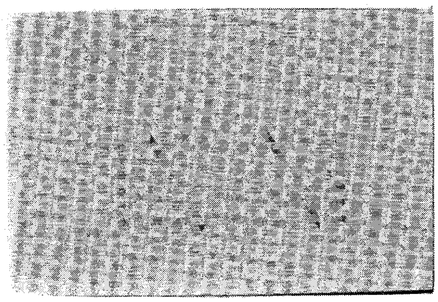
    c. A more homogeneous mix is produced because of the longer mix time.

28. Several attempts have been made to recycle without modifying the standard drum mixer plant. These attempts used direct flame heating, where all the materials enter the drum mixer simultaneously. Satisfactory mixes could be produced but emissions standards could not be met. Frequently there was a build-up of fines and asphalt in the drum which also contributed to the air pollution problem.

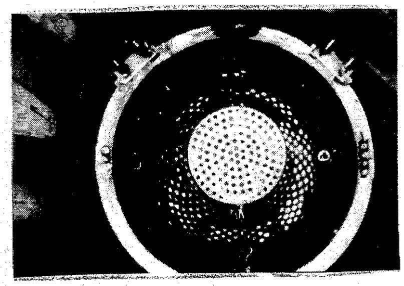
    Solutions to the air pollution problem included lowering production rates, increasing the water content of the RAP, lowering the mix discharge temperature, introducing additional air and decreasing the percentage of RAP. However, it was found that a more effective way of dealing with these problems was to modify the plant.



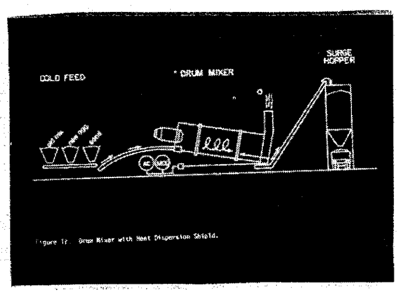
29. An early modification, known as The Mendenhall Process, was developed in the early 1970's. It was an indirect heating method in which the RAP, together with any necessary aggregates, was heated in a special drum fitted with internal tubes.



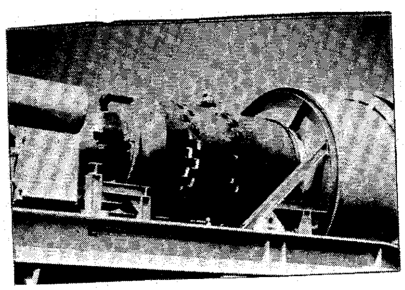
30. The RAP and the new materials entered the drum together while the combustion gases from the burner passed through the internal tubes. The heated discharged material was finally processed through a pugmill, where binder or modifier could be added. These small plants were designed to be capable of recycling 100 percent RAP. However, difficulties were experienced due to excessive build-up of material in the drum.



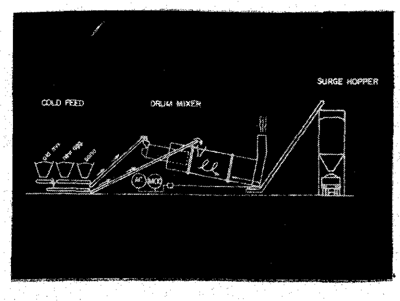
31. Another early method, the Pyrocone System, was equipped with a conical heat shield placed between the burner and the RAP. The burner flame was totally contained within the heat shield, reducing the amount of direct heat radiation and producing a more uniform distribution of heat.



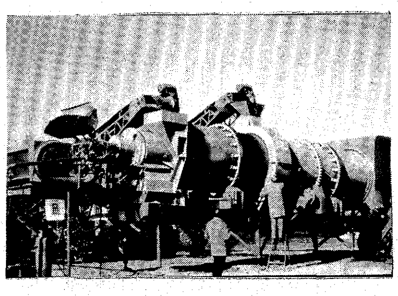
32. The RAP entered the drum with any virgin aggregate by a single conveyor at the burner end. New asphalt cement was added in and mixed further down the drum, as in a conventional hot-mix process.



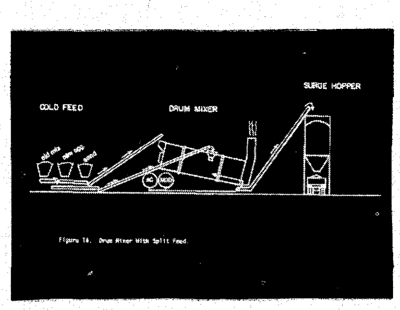
33. The Pyrocone System can recycle up to 100 percent RAP, though 50 to 60 percent is more typical. However, its main disadvantage is that water has to be added to the mix in order to achieve emission standards. This is counterproductive because the additional water has to be driven off during heating.



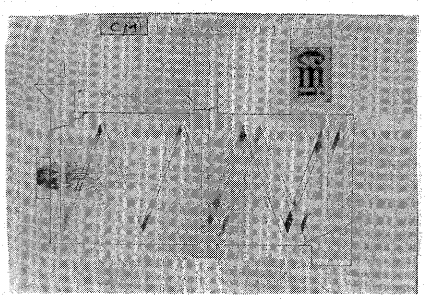
34. Heat-transfer systems have also been used on drum mixer plants. Variations include the drum-in-a-drum (pictured), tandem drum mixers and a rear entry system. None of these is commonly used today due to low recycling ratios, significantly lower production rates and their inability to produce mix at standard temperatures without high levels of emissions.



35. The most common method used today is the split feed or center entry method. In this configuration, the new aggregate enters the drum through the burner end while the RAP enters just beyond the midpoint of the drum from a separate conveyor.

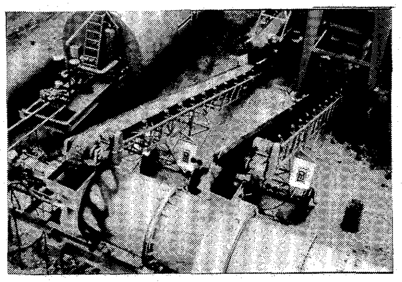


36. Depending on the percentage of RAP used, the virgin aggregate is heated to a temperature between 300 and 600^{o}F before it is mixed with the RAP and new asphalt cement midway down the drum. By this point, the exhaust gases have cooled sufficiently to keep the asphalt from burning. Heat transfer from the aggregate to the RAP continues as the mix moves down the drum.

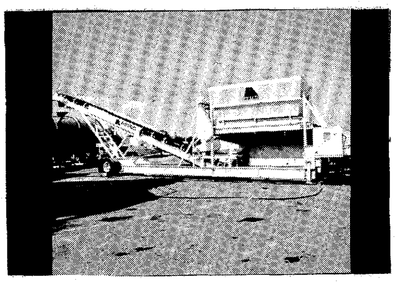


37. Split feed systems can be adjusted to handle the temperature sensitivity problems of hot recycling. For example, the drum can be lengthened, with the RAP inlet farther downstream. This gives the virgin aggregate more time to absorb heat and to release moisture. It also results in more aggregate being between the flame and the RAP.

Other modifications are possible, such as, moving the position of the asphalt line or changing the flight design of the drum, the burner design, the slope of the drum. Water and air injection systems can also be added to maintain constant gas stream temperatures.

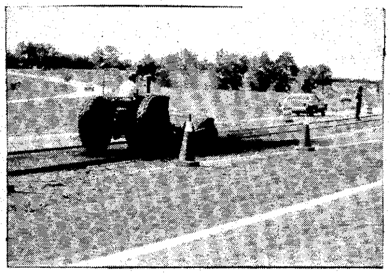


38. The split feed process can recycle 60 to 70 percent RAP, though 30 to 50 percent is more common. If the amount of virgin aggregate is more than half of the total aggregate weight, an adequate aggregate veil will be created in the dryer to protect the asphalt in the RAP.

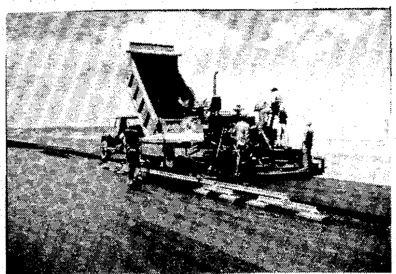


39. Conventional conveying equipment can be used to feed RAP into either batch or drum mixer plants. RAP bins should have relatively small capacity with steep sides and wide, long bottom openings to allow for easy discharge and minimal sticking problems. The RAP should be dribbled into the bin, since a unit drop could compact the RAP. Vibrators should not be used on this bin since they encourage compaction of the RAP.

40. Standard equipment and procedures can be used for spreading and compacting recycled hot-mixes. One difference between recycled and conventional mixes is that the recycled mix may be stiffer and harder to work. Additional compaction effort, quality control and monitoring will also be required.

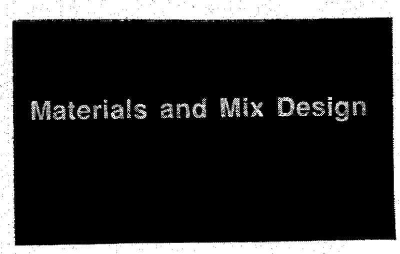


41. The milled roadway surface should be swept with a rotary broom before applying the tack coat. Since the milled surface will be rough with uncoated aggregate surfaces, more liquid asphalt will be needed than for conventional paving.

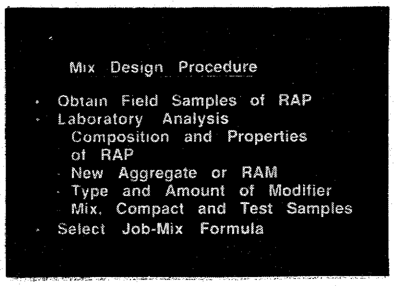


42. Paver characteristics, lift thicknesses and mix properties will influence the uniformity, laydown, compaction, and rideability of the mat. The extra fines generated by cold milling can cause the mix to be stiff, resulting in pulling of the mat and lower mat density.

43. Compaction requirements are similar to those for conventional mixes. However, the tendency for excessive dust and fines in recycled mixes may present problems in compacting lifts thicker than 1 1/2 or 2 inches. The density may be 1 to 2 percent less than for a conventional mix with the same compaction effort.



44. Numerous researchers and government agencies have investigated and adopted mix design procedures for hot recycling. Most make use of existing procedures with some additions or modifications.



45. In general, a proper mix design will include the following steps:

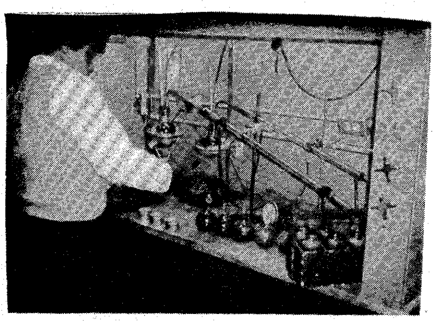
a. Obtain representative samples of the reclaimed materials,

b. Perform laboratory analysis, and

c. Select the optimum combination of components meeting design criteria.

Mix designs should be developed with actual project materials. The intent is to produce mixes with similar properties to virgin mixes. This is possible through proper mix design.

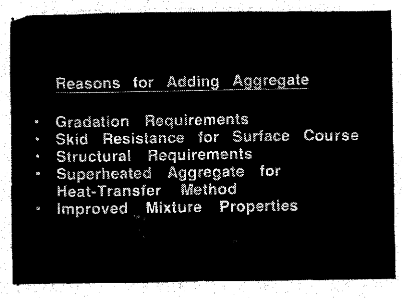
46. Representative samples of the material to be recycled must be obtained to produce a high quality mix. They can be taken from the pavement, from trucks and from existing stockpiles. AASHTO and ASTM sampling methods are available.



47. Extraction tests and asphalt recoveries (pictured) should be performed so that judgments can be made about the quality of the reclaimed materials and possible reasons for pavement distress.

Viscosity and penetration tests should be performed on the recovered asphalt, in order to determine the amount and type of modifier needed to bring the binder viscosity into the desired range.

48. The extracted aggregate should be tested for gradation, using a washed sieve analysis, as well as for durability and cleanliness. Any RAM should be tested for the same properties as virgin aggregates.



49. New aggregate or RAM will probably have to be blended with the RAP for one or more of the following reasons:

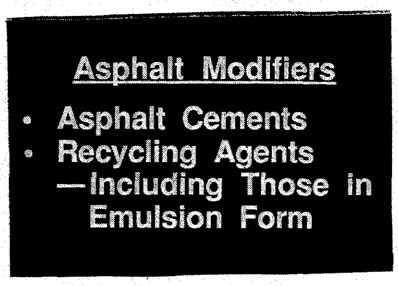
a. Gradation Requirements - The aggregate in the RAP may not meet gradation specifications.

b. Surface Friction - It may be necessary to blend coarse non-polishing aggregates into surface course mixes. At least 40 percent of the plus No. 4 fraction should be non-polishing.

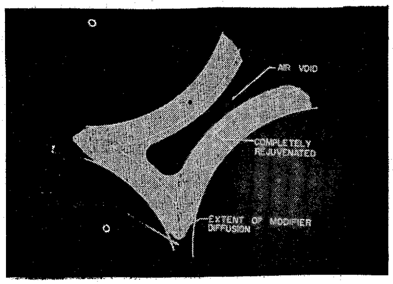
c. Structural Requirements - Increased traffic loading may necessitate increasing the thickness of the asphalt stabilized layer.

d. Air Quality Problems - A certain amount of new aggregate is needed to protect the RAP from the flame.

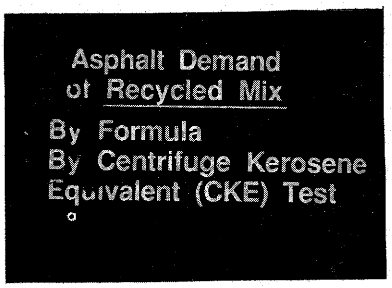
e. Mix Properties - Mixture properties, such as, stability, durability and workability can be improved.



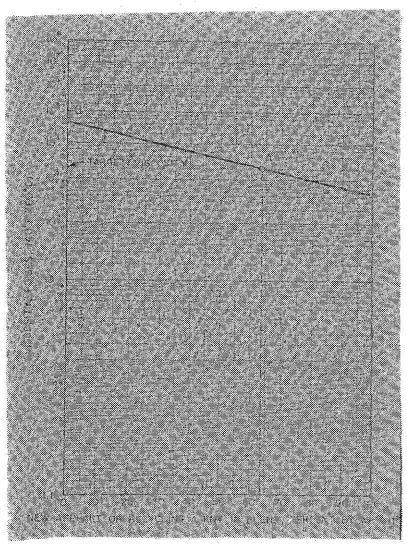
50. Older asphalt often has hardened to the point that it undesirable for re-use without modification. Various materials have been used to alter its properties. These have been called softening agents, reclaiming agents, modifiers, recycling agents and rejuvenating agents. Soft asphalt cements and commercial recycling agents are typically used as modifiers.



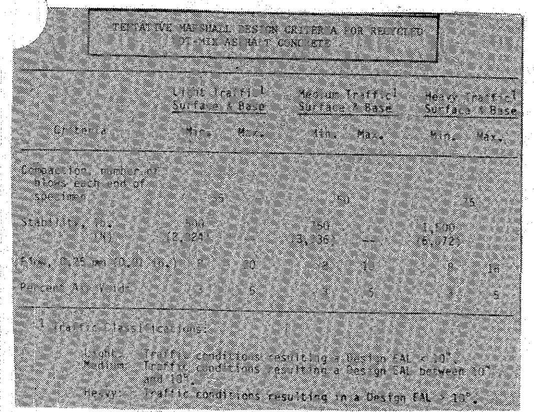
51. Samples of any modifier should be tested for compliance with standard specifications, such as AASHTO and ASTM. Currently, there are no widely accepted specifications for recycling agents. In selecting the proper grade of recycling agent, the characteristics of the binder blend are the determining factors.



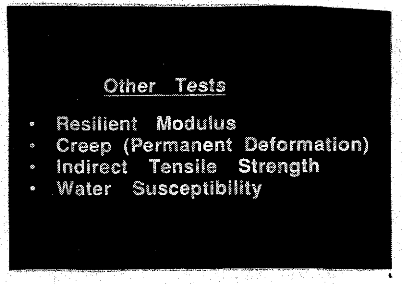
52. Before the specific grade of modifier is selected, the approximate asphalt demand of the mix must be determined. This in turn establishes the amount of modifier that must be added. The approximate asphalt demand can be determined by The Asphalt Institute's formula which is based on the amount of material passing the #8 and #200 sieves and on the absorptivity of the aggregate. An alternate method is the Centrifuge Kerosene Equivalent test.



53. Studies have shown that a linear relationship exists between the logarithm of viscosity and the percentage of modifier to be added to the mix. The percentage of modifier to be added to the mix is entered on a semi-log blending chart along with the target viscosity for the blended binder to establish Point A. The viscosity of the RAP binder is entered on the left side of the chart to establish Point B. A line drawn through these two points to the right gives the required viscosity of the modifier. The modifier should then be blended with the recovered asphalt and subjected to viscosity tests to determine if the predicted viscosity is accurate.

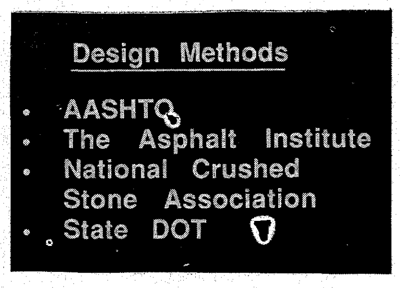


54. Once the approximate amount, type and grade of modifier have been determined, a laboratory evaluation should be conducted using Marshall or Hveem equipment, procedures and design criteria. Specimens of compacted recycled mix with a range of binder contents should be tested for air voids, stability, flow, VMA and density.

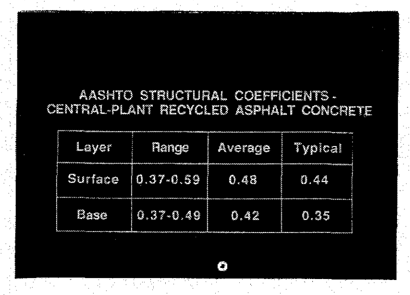


55. Other tests can be used to determine the properties of the mix. These include resilient modulus tests, creep tests, and tests for thermal cracking and water susceptibility.

Stripping tests are an important part of mix design, especially if the RAP is obtained from pavements that have experienced moisture damage. The Lottmann and the Root-Tunnicliff tests can be used to assess the potential for stripping.



56. The structural design of pavements using recycled mixes can be performed using the same procedures as for conventional pavements. A number of design methods are available.

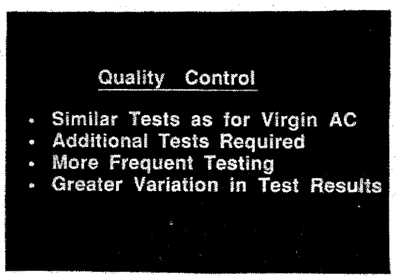


AASHTO STRUCTURAL COEFFICIENTS - CENTRAL-PLANT RECYCLED ASPHALT CONCRETE

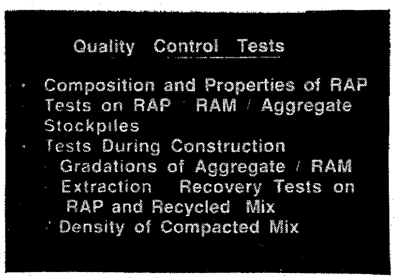
Layer	Range	Average	Typical
Surface	0.37-0.59	0.48	0.44
Base	0.37-0.49	0.42	0.35

57. AASHTO layer coefficients have been developed for hot recycled surface and base courses. The Asphalt Institute method assumes equivalency between recycled and new materials. However, due to the limited performance data base for recycled materials, the question of long-term equivalence to conventional materials is unanswered.

58. The state-of-the-art of designing and constructing pavements composed of recycled materials has advanced to the point where hot-mix asphalt recycling can be considered as an alternative to conventional procedures for most paving jobs. Specifications will normally have the same requirements as virgin mixes.

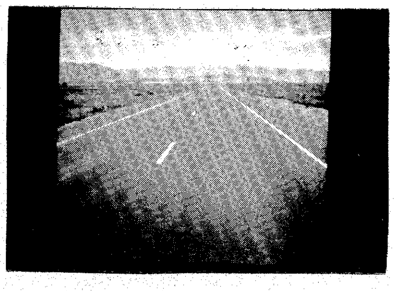


59. Quality control and acceptance tests for conventional mixes can also be used for hot recycled mixes. However, additional tests are usually required to monitor the consistency of the RAP gradation and the asphalt viscosity. More frequent testing is required for recycled mixes because of the greater variation in test results.



60. During production, the gradation of the new aggregate and the extracted RAP should be monitored. Viscosity tests on the extracted asphalt should be performed to ensure the consistency of the blended binder. Extractions of RAP usually take more time than for conventional mixes since more washings are required to extract the hardened asphalt.

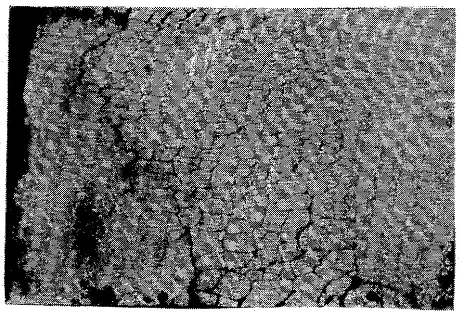
Due to the variability inherent in recycling, the mix design should not be changed during production unless several tests fall outside specifications, or if tests are significantly off design values. Individuals should not react too quickly to adjust asphalt content during production based on a single test result, especially when the average of several tests is close to design requirements.



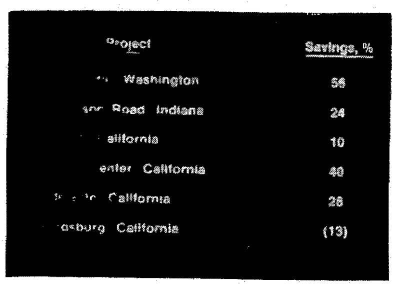
61. In summary, hot recycled asphalt mixes can be designed, produced, and placed similarly to conventional mixes. Some modifications are however required. Additional testing will be needed to design and to control the mix. However, with proper care high quality pavements can be built using hot-mix asphalt recycling.

COLD-MIX ASPHALT RECYCLING

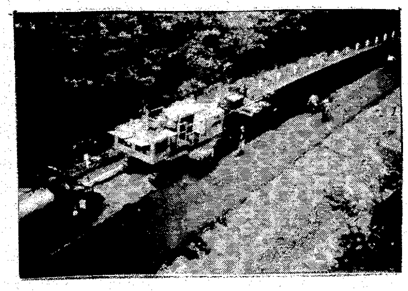
1. In cold-mix asphalt recycling, reclaimed roadway materials are mixed without heat, spread on the roadway and compacted. The reclaimed materials may consist of reclaimed asphalt pavement (RAP), reclaimed aggregate materials (RAM) and untreated foundation materials. New aggregates, modifiers (asphalt and recycling agents) and stabilizers (lime, fly ash and portland cement) can also be added. The mixing can occur either on the roadway or at a central plant.



2. Asphalt pavements can deteriorate in a number of ways. Repair methods have generally involved the addition of thickness or the complete removal and replacement of the existing pavement. While both can give satisfactory results, they do not take advantage of the remaining value of the existing paving materials. Cold-mix asphalt recycling is able to recondition the old deteriorated pavement and turn it into a good stabilized base.



3. Cold-mix asphalt recycling has been promoted as an energy saver. It also saves money and materials. Cost savings range from 10 to 50 percent. Other advantages are that structural improvements can be made with only minor changes in profile and all types of distress can be treated.



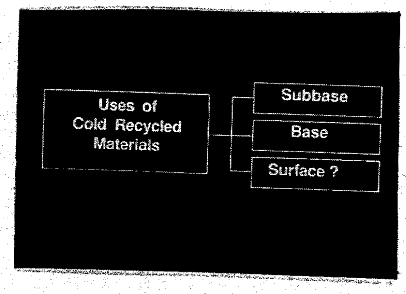
4. Some considerations in cold-mix asphalt recycling include:

   a. Quality control is not as good as for hot-mixes,

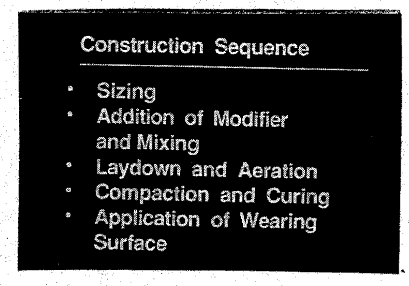
   b. Traffic may be disrupted for longer periods,

   c. Curing is required for strength gain, and

   d. Strength gain is affected by temperature and moisture conditions.



5. Cold-mix asphalt recycling is used mainly for base construction. Although, in some cases it has performed acceptably as a surface, usually an asphalt concrete overlay or a surface treatment is required.



6. There are five basic steps in cold-mix asphalt recycling:

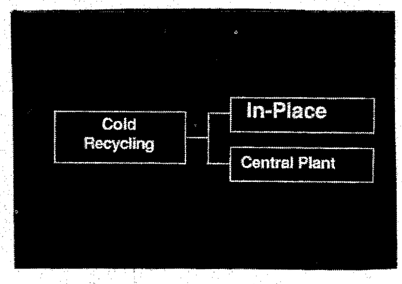
   a. Pavement breaking and sizing,

   b. Addition and mixing of aggregate, modifier and/or stabilizer,

   c. Laydown and aeration,

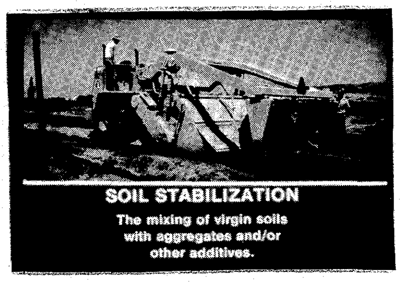
   d. Compaction and curing, and

   e. Application of a wearing surface.

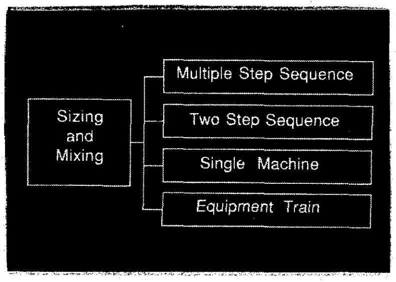


7. The first step in any recycling process is to rip, scarify, or mill the existing pavement to a specified depth. The broken material can then be either reduced in size and mixed in-place or it can be hauled to a central plant to be crushed, stockpiled and mixed.

The choice of method depends primarily on the availability of equipment. In-place recycling is more common, however, central plant mixing provides better quality control and a more uniform mix.



8. Much of the in-place sizing and mixing equipment was developed for soil stabilization work.



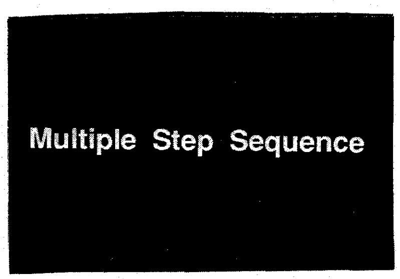
9. In-place sizing and mixing can be roughly separated into four general categories. Due to the wide variety of equipment available for this work, there is some overlap between the categories.

   a. Multiple step sequence,

   b. Two step sequence,

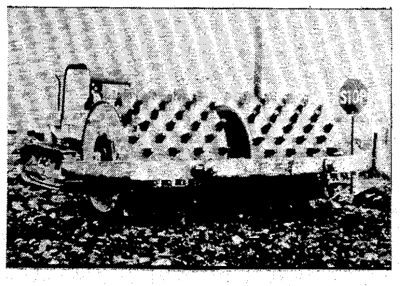
   c. Single machine, and

   d. Equipment train.

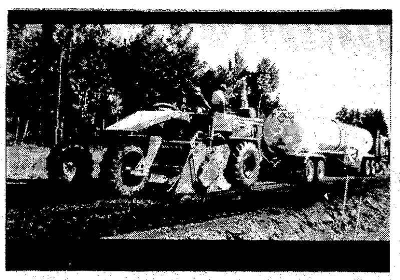


10. The multiple step sequence consists of breaking, pulverizing and mixing the existing pavement and placing the new layer using a number of separate operations. Numerous methods are available for breaking up the existing pavement. Some employ conventional equipment while others make use of specially designed equipment.

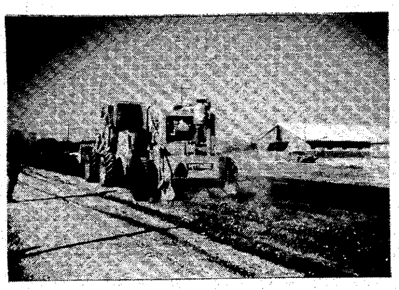
11. The simplest method for breaking the pavement is with a motor grader or dozer equipped with ripper teeth. This method is efficient with thin layers but tends to dig deeper than desired and produces large chunks of RAP.



12. Sheepsfoot or grid rollers, rotary mixers or hammermills are used to further pulverize the RAP. Multiple passes will be required to achieve the required size reduction.



13. Mixing of the RAP with modifiers and stabilizers can be done by motor grader or traveling mixers.

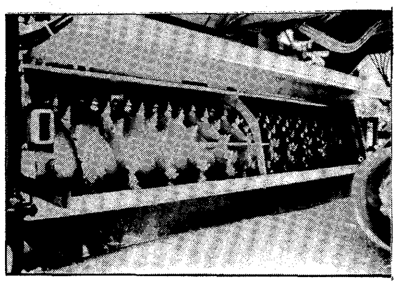


14. The multiple step sequence has the advantage that it uses readily available equipment. However, it has a number of disadvantages. It cannot be used on projects where only partial depth removal is planned. There is usually some mixing between the RAP and the base and some oversized RAP may remain. Production rates are slow and there may be problems with equipment coordination and traffic control.

Two Step Sequence

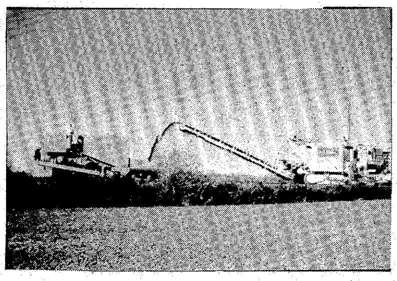
15. The two step sequence combines the breaking and sizing steps into a single operation using cold milling machines. Modifiers and stabilizers are added and mixed in the second step.

16. Cold milling machines have rotating drums lined with cutting teeth to grind the old pavement. They provide accurate depth and profile control, the ability to pulverize and size in a single pass and high productivity. However, they require trained personnel, have higher operating costs and may generate excess fines.

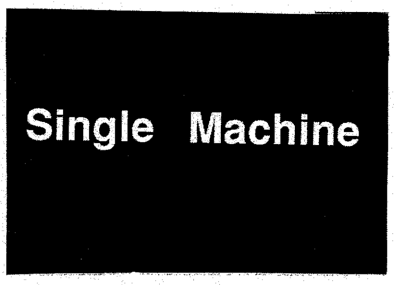


17. Cold milling machines can operate in either an up-cutting or a down-cutting mode. For partial depth cuts, the up-cutting mode is generally more economical. It provides a more accurate cutting depth and causes less damage to the underlying layer. Up-cutting may produce significant amounts of oversized RAP. Down-cutting results in smaller sized material but may cause damage to the underlying base.

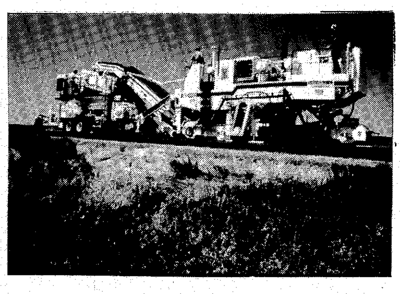
The productivity of a milling machine is a function of the resistance of the pavement to the penetration of the cutting teeth. Two important factors affecting this resistance are material quality and depth of cut. Harder aggregates will increase tooth wear and decrease productivity. Two passes will probably be more efficient for cuts deeper than 3 to 4 inches.



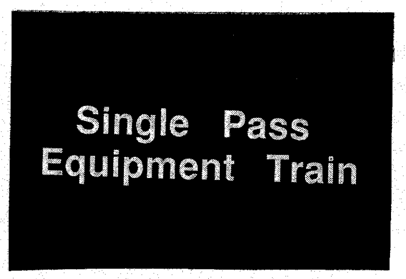
18. Soil stabilization mixing equipment and traveling mixers can be used to add and mix any modifiers. In this view, the RAP is fed from the cold milling machine to a traveling mixing paver.



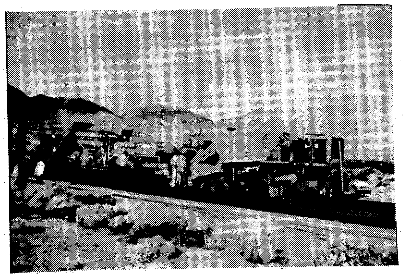
19. Single pieces of equipment have been developed that are able to break, pulverize and add modifiers and stabilizers in a single pass.



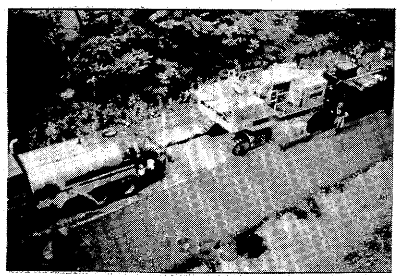
20. In this view, a portable crusher has been attached to a cold milling machine. The milled RAP is conveyed to the top of the portable crusher. After crushing, the recycled mix is deposited in a windrow behind the crusher.



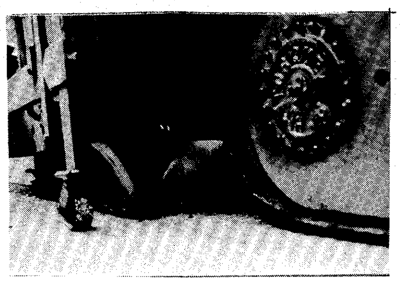
21. Several contractors have developed single pass equipment trains able to recycle large quantities of material. The train usually consists of a cold milling machine, portable crusher, traveling mixer and a laydown machine.



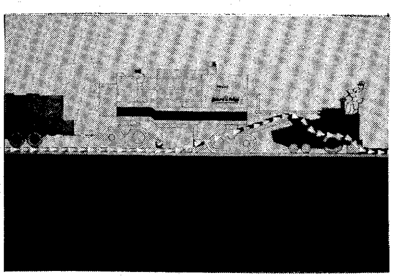
22. In this train, the material is being processed from left to right. A cold milling machine discharges the RAP into the crusher unit which passes it over an 1 1/2 inch scalping screen. Any RAP retained on the screen is returned to the crusher. Eventually, all of the RAP passes the screen and is conveyed to the traveling mixing paver.



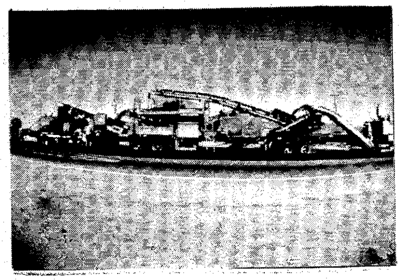
23. Another train consists of an asphalt truck, cold milling machine and paver.



24. In this sequence, an asphalt emulsion is sprayed in front of the cutting head of the cold milling machine.



25. The pavement was milled to a 3 1/2 to 4 inch depth and reduced to a maximum size of 1 1/2 inches. The mix is then deposited directly into the paver hopper. On this project, the production rate achieved was one lane-mile per day.



26. The single pass equipment train has similar advantages and disadvantages to the two step and the single machine methods since it uses the same types of equipment.

27. There are a number of ways of mixing the RAP, modifier, stabilizer and new aggregates. Blade mixing with a motor grader is the simplest method but it can be slow and inefficient. Also, it does not control the uniformity of the mix as well as the traveling mixing machines. The basic sequence for blade mixing involves:

    a. Using a motor grader to windrow the RAP and any new aggregates and RAM,

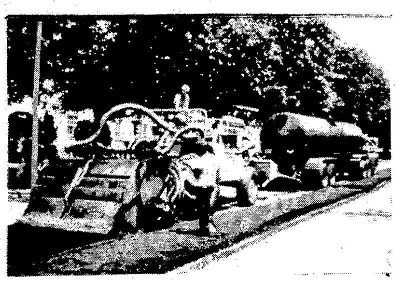
    b. Adding water, if needed,

    c. Blading the windrow across the road to blend in the water,

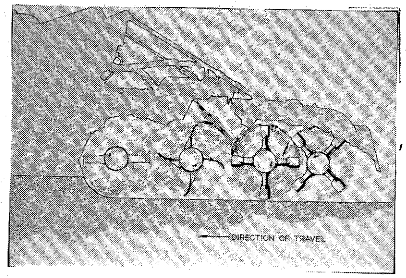
    d. Reshaping into a windrow and adding the modifier, and

    e. Working the mixture back and forth until a uniform mix and proper fluids content is achieved.

    A good feature of blade mixing is that the mix is aerated and its fluids content is lowered as it is bladed across the roadway.

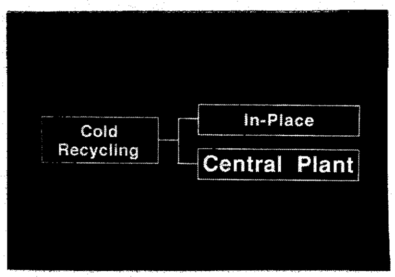


28. Mixing operations are often performed with single and multiple transverse shaft rotary (flat type) mixers. The modifier can be applied either to the windrow by an asphalt distributor or by a spray-bar in the cutting chamber.



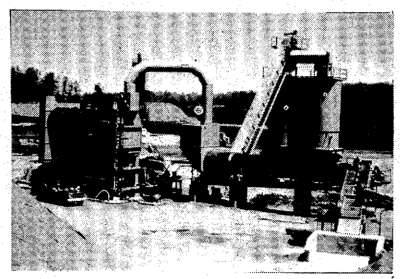
29. With this system, sizing and mixing can occur in a single pass if the RAP is adequately reduced in size. However, several passes are usually required to achieve a uniform mix.

30. Hopper type or travel plant mixers have pugmills that can mix the RAP with the modifier at a controlled rate, as they move along the road. There are several options when using these mixers. One is a windrow pickup attachment for loading the RAP directly from the road into the pugmill. Another is to feed the RAP and new aggregate into the plant's hopper by truck or conveyor.

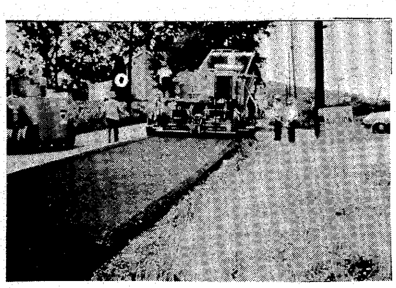


31. Central plants can also be used for cold-mix asphalt recycling. Their advantages include better quality control, easier proportioning and blending of new aggregate, and higher production rates. However, there are added hauling costs and the potential for increased traffic disruption. Central plants may be economical in locations where a plant is already available.

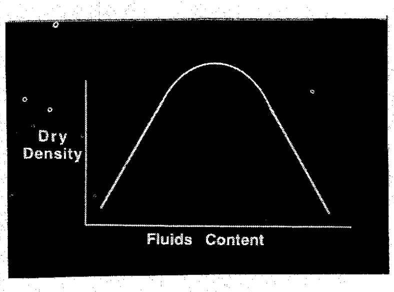
32. A number of options for removing and sizing RAP are associated with central plant cold-mix asphalt recycling. These vary based on the amount of sizing done on-site. The method chosen will probably be determined by equipment availability and the acceptability of extended road closures.



33. Central plants can recycle 100 percent RAP mixes, since no heat is applied. Proportioning of the RAP, RAM and new aggregate is based on cold feed rates, since the batch plant screens are usually removed. A scalping screen should be used to remove oversized material. The plant should have the capability of accurately adding water as well as modifiers and stabilizers to the mix.

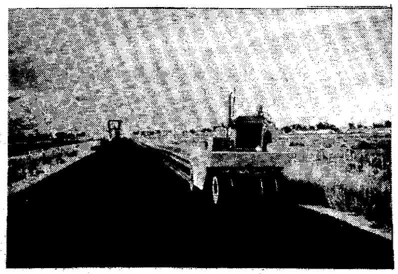


34. Conventional equipment can be used to lay and compact cold recycled mixes.



35. Achieving proper fluids content, modifiers and water, is a critical part of the laydown and compaction process. Some amount of fluids are required for compaction. They also help to prevent sticking to the screed and reduce tearing of the surface.

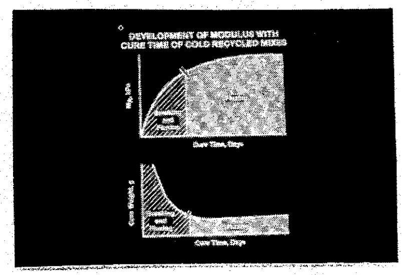
Excess fluids lower the stability of the mat during rolling. The pavement will have lower density and moisture may be sealed in. After laydown, rolling should be postponed to allow the mat to cure to a moisture content of about 1 1/2 percent.



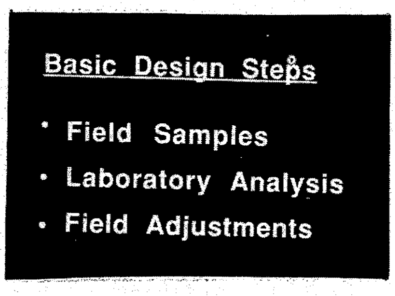
36. The Asphalt Institute recommends that cold-mixes be placed in compacted lifts of 3 inches or less and that curing times of two to five days be allowed between lifts. Rolling patterns should be established by constructing test strips and using a nuclear gauge to monitor density.

37. Almost all highway agencies cap cold recycled layers with a hot-mix overlay or surface treatment. The thickness of this wearing surface is based on the predicted traffic loadings. It is typically placed several days after the recycled material is compacted, to provide curing time for strength development. To prevent raveling before the cap is placed, the base is sometimes sprayed with an asphalt emulsion fog seal.

38. The Asphalt Institute and Chevron have recommended mix design procedures for cold-mix asphalt recycling. However, there is currently no standardized procedure. The main difficulty is that design criteria cannot be easily established. For example, cold-mixes usually have higher air voids contents than hot-mixes.



39. While these methods have similarities to hot-mix design procedures, certain differences must be considered. These involve the time-temperature effects associated with the presence of water and volatiles, and the slower binder softening rate. As illustrated, the mix gains strength as it cures.

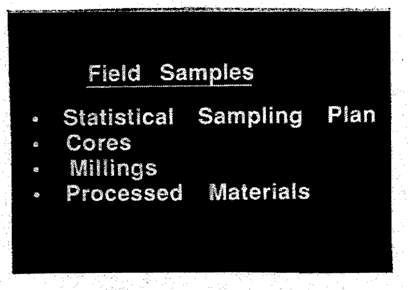


40. As with hot-mix recycling, certain basic steps must be included in the mix design procedure for cold-mix asphalt recycling.

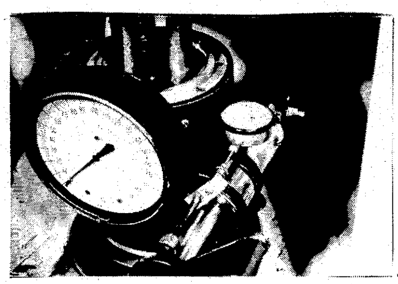
   a. Obtain representative field samples,

   b. Perform laboratory analysis, and

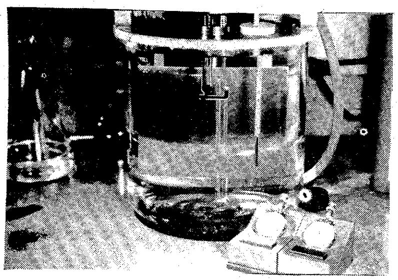
   c. Select the optimum combination of components as initial target values and adjust in the field.



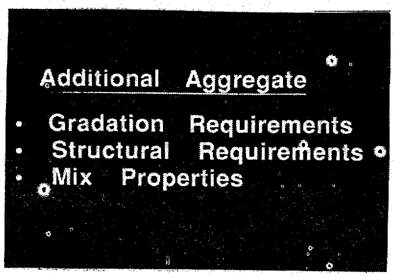
41. Statistical methods are available for obtaining random samples of reclaimed material. The Asphalt Institute recommends that a minimum of five samples per mile or one sample per block be taken. The design, construction and maintenance history of the existing pavement are also important sources of information.



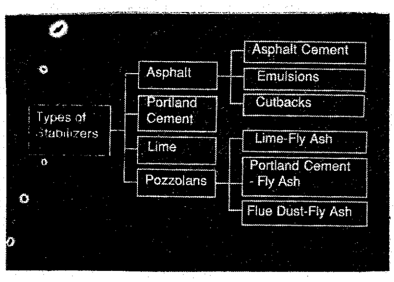
42. In general, laboratory methods for virgin cold-mixes, empirical formulas or past experience are used to design cold recycled mixes. Any mix design procedure should always include laboratory testing. Here, a specimen is being tested for stability.



43. Extraction and recovery tests should be performed on each field sample to determine its asphalt content. The recovered asphalt should be tested for penetration and viscosity (pictured). Extracted aggregates should be tested for gradation and quality. Any RAM and new aggregates should be tested for gradation, fractured faces and cleanliness.

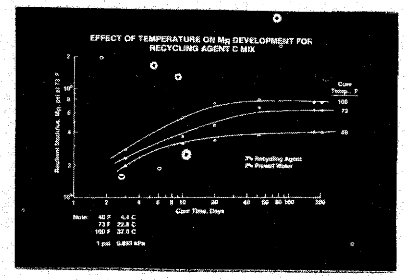


44. Based on the field samples, judgments can be made concerning the quality of the reclaimed material and possible reasons for pavement distress. New aggregate or RAM may have to be blended with the RAP to satisfy gradation requirements. New aggregate and binder may be added if extra thickness is required. Mix properties, such as, stability, durability and workability can also be improved.

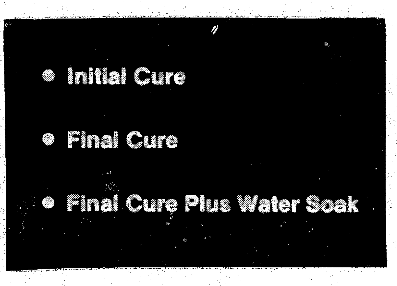


45. Asphalt products used as modifiers include slow or medium setting emulsified asphalts, cutback asphalts, heated asphalt cements and emulsified recycling agents. Emulsified modifiers have the advantage of being liquid at ambient temperatures, are easily dispersed throughout the mix and do not have emission problems. Some cold-mixes use heated modifiers such as soft asphalt, cutback asphalt, and non-emulsified recycling agents.

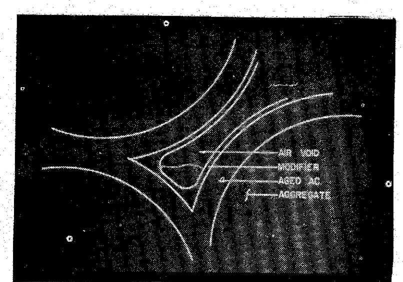
Water may be needed to help disperse the modifier during mixing. A small amount of portland cement or fly ash can help to stabilize the recycled mix and reduce curing time.



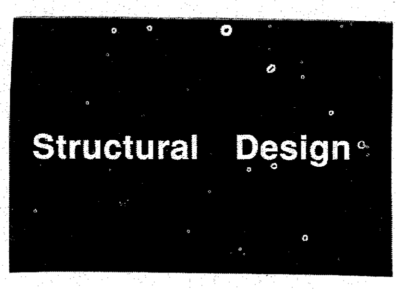
46. Softening of the aged asphalt is a time and temperature dependent process. The reaction between the aged asphalt and the modifier will not take place everywhere in the mixture at the same time. This effect causes problems when trying to establish the target amount of modifier to add.



47. Also important are changes in stability and strength as the mix cures. Laboratory evaluations of these properties should be made at both the initial and ultimate stages of curing. In addition, because of the detrimental effects of water on cold-mixes, moisture damage testing of the specimens should be included in the mix design procedure. Such testing may indicate the need for anti-strip additives.

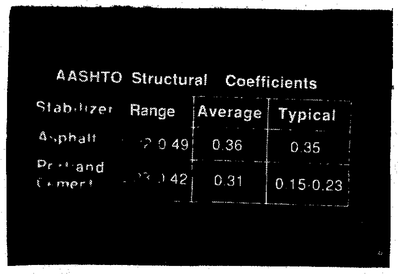


48. There is some question as to the value of the aged asphalt as binder when mixing takes place at ambient temperatures. Very hard, oxidized asphalt may act as aggregate and because of this, the effective binder content, as opposed to the total asphalt content, will govern the performance of the mix. The choice of modifier will probably depend on previous experience on similar projects. A relatively small amount of emulsified recycling agent may be effective in softening the aged asphalt if adequately dispersed and mixed.



49. The load carrying capacity of pavements is affected by the strength and thickness of each layer, the traffic loadings and the effect of environment. The load carrying capacity of recycled materials can be established in a manner similar to that for virgin materials.

50. A number of thickness design procedures have been developed. These include the AASHTO, U.S. Forest Service, Asphalt Institute, Shell, and Chevron methods as well as several State highway department methods.



51. AASHTO layer coefficients have been developed for cold recycled mixes from a variety of test sections. A value between 0.30 and 0.35, as compared to 0.44 for hot-mix asphalt concrete, is appropriate. However, engineering judgement should be exercised when assigning coefficients.

The Asphalt Institute's design method is based on the use of emulsified asphalt mixes and is applicable to cold recycled mixtures. As with the AASHTO method, traffic and subgrade strength are input parameters. The design charts give the combined thickness of the recycled base and the wearing surface.

52. Specifications should focus on the properties of the reclaimed material and the recycled mix rather than on the exact methods of construction. They should permit the use of central plants or in-place mixing equipment, provided the final mix meets requirements. Any type of pulverization and size reduction equipment should be allowed so long as the depth of cut is maintained within tolerances and 100 percent of the reclaimed material passes a designated sieve size.

Material Specification

- Aggregate Sizes
- Asphalt Modifier

53. Materials specifications will deal with aggregate gradation, asphalt modifiers, moisture content and density. Most specifications limit the top size of the RAP. Due to variability in the RAP and in the recycling process, gradation requirements will have to be more flexible than for hot-mixes. However, consideration should be given to the amount dust in the mix. A maximum of 12 percent is reasonable.

The modifier should conform to AASHTO, ASTM or State specifications for emulsified asphalt, cutback asphalt, or asphalt cement. The equipment for adding modifiers, water and stabilizers should be capable of accurate application rates.

Problem Areas

- Depth of Removal
- Degree of Pulverization
- Uniformity of Mixing
- In-Place Density
- Curing
- Protection from Traffic

54. Potential quality control problems involve:

a. Depth of removal and degree of pulverization,

b. Blending of the new aggregate, RAM, water, stabilizers, or modifiers,

c. Distribution of modifiers, water, or stabilizers,

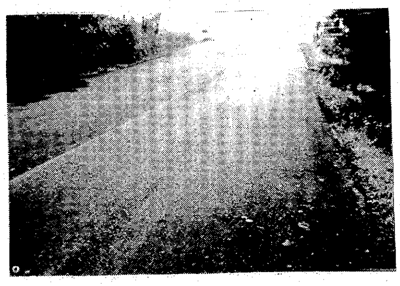
d. In-place density,

e. Curing, and

f. Protection from traffic.

It can be difficult to relate the in-place density of cold recycled mixes to laboratory prepared specimens because of temperature, fluids content and materials variations. Agencies have specified a percentage of theoretical maximum density or laboratory density or have set target densities. Agency experience will probably determine which type of density specification is appropriate.

Testing by Purdue University found considerable variation in mix properties of cold recycled pavements. The Hveem stability of cores obtained after placement of the surface course ranged from 10 to 40 and densities ranged from 133 to 155 lb/ft^3. In spite of these variations, the subject pavements have performed well for over three years. However, long term performance data is still lacking.



55. In summary, cold-mix asphalt recycling is not as well defined a process as either conventional hot-mix construction or hot-mix recycling. The resulting mat will not have the same quality or strength. Cold-mix asphalt recycling is probably most effective for reworking an old deteriorated asphalt pavement into a stabilized base. It reuses existing materials and can produce significant savings in cost and energy.

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