HOT AND COLD RECYCLING OF BITUMINOUS MIXTURES

A Thesis Submitted to the
Graduate School of Natural and Applies Sciences of
Dokuz Eylül University
In Partial Fulfillment of the Requirements for
the Degree of Master of Science in Civil Engineering ,
Highway and Transportation Program

by
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November , 1997
IZMIR

M. Sc. Thesis Examination Result Form

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ACKNOWLEDGEMENTS

The author is grateful to Prof. Dr. Mehmet ULUÇAYLI , the advisor of the Master Thesis , for his valuable guidance and support. He thanks Assoc. Prof. Dr. Çetin VARLIORPAK for his great help. The author would also like to thank Serhan Tanyel For his valuable helps and efforts during various stages of this study.

Additionally , the author would like to thank Süha ARAY , The Head of Bituminous Mixtures Laboratory , General Directorate of State Highways for his interest to this subject.

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ABSTRACT

The useful life of an asphalt pavement depends on a number of factors. The most important ones are:

- The volume and weight of the traffic
- Weather
- Quality of the materials
- Subgrade strength
- Drainage
- Quality of Construction

Due to the decrease in good quality sources of aggregate , the rise in hauling costs , the high cost of the equipment as well as the construction; during the last years apart from the conventional methods , significant changes have been witnessed in approaches concerned with the highway design , construction and particularly with the increasing interest in the matters of conservation of natural sources. This leads to the reuse of existing materials -recycling.

With the rapid increase in the volume of traffic in Turkey as well as the increase of legal axle load to 13 tons , tandem axle load to 19 tons , a feasible solution is being searched during the last few years.

In this study modern techniques for recycling have been described and laboratory experiments have been performed to see the usability of this method in Turkey.

In chapter I of this five part study some definitions are given , information on the historical developments of recycling is provided , and reasons for preference are investigated.

In chapter II a classification of recycling method is presented as hor and cold recycling ; in -situ and in plant. And also emphasis is placed upon the common equipment types that different countries use.

In chapter III , laboratory tests are performed on the asphalt samples which have been extracted from the Ankara Street -an express way passing along the Campus of the Ege University in Bornova. Marshall Briquettes are prepared using the 20% and 30% of the old pavement , and stability tests are performed on each of the briquettes.

In chapter IV , a cost analysis is made in visual-basic program to see the benefits and disadvantages of the recycling methods.

In the last chapter of this study , the results that are obtained from the laboratory tests and visual basic program are summarized. Not only the disadvantages and advantages but also the usability of this method in Turkey is discussed.

ÖZET

Bircok ülkede 1970'lerin ortalarına dogru büyük bir petrol krizi yaşanmış , bununla birlikte dünyamız motorlu taşıt sayısındaki hızlı artışa tanık olmuştur. Çevre kirlenmesinin en azda tutulmak istenmesinin sonucunda da yol tasarımı , yapımı bakimi ve kullanımı ile ilgili bir çok çalışmada köklü değişikliklere gitme gereği duyulmustur. Bu köklü değişikliklerin en önemlilerinden biri de deforme olmus yol kaplamalarının yeniden kullanılarak değerlendirilmesidir.

Yukarıda belirtilen durumlar ülkemiz için de sözkonusudur. Özellikle 70'li yılların ortalarına doğru görülen hızlı trafik artışının yanında agir taşıt sayısının artması bu arada ağırlık kontrolü yapılmaması yol üsy yapısının bozulmasına sebep olmaktadır.

Bunun yanında 16.6 1985 tarihinden itibaren tek dingil için 13 ton , tandem dingil için 19 tona izin verilmesi belirtilen durumu daha da ağırlaştırmış , daha düşük dingil yüklerine göre projelendirilmis olan yol ağının bakım ve onarımı için büyük harcamalar gerektirmistir.

Ülkemizde hala yol bakım ve onarımında geleneksel yöntemler kullanılmaktadir. Bu durumda beraberinde bir çok sorunu getirmektedir. Bozulmuş olan yol kaplamalarının onarımı için aşınma tabakası üstüne yeni asfalt karışımları serilmekte böylece yol sathının yüksekliği artmakta bu da ortaya drenaj gibi çok önemli bir sorunu çıkarmaktadır. Drenaj sisteminden yoksun olan bir yolda ise sık bakım ve onarım calışmalarından dolayı maliyet ve enerji artışlari olmaktadır.

Bes bölümden oluşan calışmanın ilk bölümünde yeniden kullanım yönteminin tanıtımı , tarihi gelişimi ve tercih edilme nedenleri konusunda bilgiler verilmektedir.

Ikinci bölümde bu yöntemin çesitli açılardan sınıflandırılması yapılarak “yerinde” , “merkezi tesiste” sıcak ve soğuk kullanım olmak üzere iki grupta toplanan seçeneklerin karayollarında uygulanması incelenmiştir. Ayrıca çesitli ülkelerin bu uygulama türü için seçtikleri ekipman tipleri üzerinde durulmustur.

Üçüncü bölümde yeniden kullanılmış karışımların hazırlanması ele alınmıştır. Ege Üniversitesi Hastanesi önündeki Ankara Caddesi üzerinden alınan bozulmus asfalt örneklerinden %20 ve %30’luk miktarlar kullanılarak briketler hazırlanmış ve üzerlerinde Marshall Stabilite deneyleri yapılmıştır.

Dördüncü bölümde yeniden kullanım yöntemine ilişkin maliyet analizi üzerinde durulmuştur. Fayda ve zarar hesaplamalarına ilişkin visual basic programı yapılmıştır.

Son bölümde ise calışmalardan elde edilen sonuçlara yer verilmis ve yeniden kullanım yönteminin avantaj , dezavantaj ve ülkemiz için kullanılabilirliğine değinilmistir.

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CHAPTER ONE
INTRODUCTION

1.General View

The purpose of this study is to describe modern techniques for recycling bituminous materials , survey the technical literature relating to these processes in order to assess the possibilities of using these techniques beneficially in Turkey.

Recycling bituminous materials has generated considerable discussion and development in the last decade. While it is not a new idea recent developments appear to be in a response to the desire of many countries to reduce their dependency on imported crude oil and the derivative product: bitumen. Many countries have recognized that the older section of their highway networks, which are in need of reconstruction represent rather less of an economic burden than was originally feared, since they contain valuable assets which can be recycled.

2. Recycling Through out the World

It would appear that the United States Of America has lead the technological development of modern recycling and while recycling is not practiced nationwide, it has become common practice in many states. Other countries which appear to be interested in developing recycling processes include India, South Africa ,Finland, Germany and France.

Taking into consideration , the rapid increase in the volume of traffic in Turkey in recent years -particularly commercial vehicle traffic -in addition the rapid increase in maximum axle load limits , an approaches becomes possible under the Transportation Master Plan which will increase the load carrying capacity of the highway network and which will give currency alternatives in maintenance and rehabilitation referred to as preservation and renewal. Unfortunately except a few experimental sections in our highway system neither cold recycling nor hot recycling have been applied in a large scale in Turkey yet.

3. Objectives of Recycling

As mentioned above , the recent increase in the price of bitumen is a major factor in prompting the development of recycling processes. This has caused a substantial change in the balance of raw material cost per tonne of asphalt produced.

For example , in 1973 bitumen represented about 54% of the raw material cost of each tonne of asphalt produced in Great Britain. By 1979 this has increased to about 80%.Since 1979 the price of bitumen has continued to rise more rapidly than the price of stone, so that in Great Britain the figure of 80%is now exceeded. Material is removed from the surface of pavements during normal maintenance and reconstruction operations. In many cases this material is treated as waste and dumped as if it has no value. However it may be used as a fill material 2.50 pound/tonne. Assuming zero value for stone, this leads to a cost of about 30-40 pounds bitumen in a reclaimed surfacing material. The cost of new bitumen is about 150-160 pounds/tonne. Thus the raw material cost to the asphalt manufacturing industry can be reduced by as much as 75 % by the implementation of recycling producers. This scale of reduction should be very attractive to any manufacturing industry.(UNDP* , 1984)

Following on from this case for recycling can be developed in three distinct areas:

*UNDP=United Nations Development Program

3.1 Benefits to community

The road surface is the hardware of the transport network and most of it is built with bituminous material. The countries of Europe are heavily dependent on their highway system for the transport of raw materials, manufactured goods and food. Thus any saving in the cost of materials used for the construction and maintenance of the highway network represents a saving to community who pay for the system, and to the individual industries whose transport costs increase as the general condition of the road deteriorates.

3.2 Energy Conservation

Recycling processes themselves conserve energy. Recycling asphalt reduces demand for new bitumen and saves energy at the refinery. Reusing stone reduces the need to win stone by quarrying and for the subsequent processing ,thus saving the cost of energy expended in these processes. It is normal to use stone with certain characteristics for road construction. The geology of some areas does not include the appropriate types of stone and so this material may have been imported stone, thus will save the energy expended in transporting it.

Finally bitumen refineries have to compete with oil fired power stations for heavy crudes , and so a reduced demand for bitumen will make more of this resource available for the generation of electricity.

3.3 Raw Material Conservation

The discussion above has indicated that recycling could reduce demand for stone and bitumen. Both of these items are resources with a finite life. While in some areas stone is plentiful, in many areas it is not, and in any case the source of supply is not infinite. Thus deposits of the high grade stone desirable for road construction will be conserved.

"The case for the conservation of crude oil is much more immediate and is given a very high priority in many European countries. Savings through recycling can make a significant contribution in this area"(UNDP , 1984)

3.4 Environmental Effects

The most crucial effect of recycling is the benefit to environment. In Turkey before strengthening of deteriorated urban or rural roads bituminous materials are generally removed and deposited outside the right of way. This inevitably represent an economic loss and causes environmental problems as well as health problems. Utilization of hot and cold mix recycling techniques may provide significant benefits to the country.

4 Definition of Recycling Processes

The following definitions are given as basis for the general discussion of recycling processes which follows.

4.1 In-situ recycling

In-situ recyling is a process in which bituminous paving material is broken up , remixed and rolled to a finished surface in place. The process can be performed either with or without the application of heat. New bitumen , new aggregate , modifying agents and new mix may be added as required.

4.2 Central Plant Mixing:

It is a process in which reclaimed material is combined with new aggregate , new bitumen and / or modifying agents at a central plant to produce a paving material. The materials may be either hot or cold when processed.

CHAPTER TWO
TYPES OF ASPHALT RECYCLING

2.Hot and Cold Mix Recycling Processes

2.1 Cold Mix Recycling Process

For many years the trend in road construction has been to devote more attention to adequate dimensioning of the entire road structure and the necessary load-bearing capacity. It was recognized that it is not merely sufficient to make the. wearing course from a high quality asphalt concrete but the base courses of a road form the important foundation.

In the search for cost-saving construction methods, i.e. saving landfall space and new construction materials, the idea arouse to reuse the high quality materials in the actual road structure. Environmental awareness which has intensified in recent years resulted in so much attention being paid to recycling that it was prescribed by law in Germany.(Wirtgen Company , 1992)

It was a matter of course that Wirtgen which has been a pioneer in the recycling of construction materials for many years, in Windhagen-West Germany developed materials ,the cold recycling method.

The process is performed with the cold recycler. DC-R, a machine type developed on the basis of the successful cold milling machines, which

- permits the complete re-use of milled material
- allows the in-situ material to be selectively used as an unbounded or bonded base course
- is used equally well as a cold recycler and cold milling machine
- allows 100% material recovery.(Wirtgen Company , 1992)

The cold recycling process can be employed on all roads. The main field of application is the rehabilitation of the minor and country roads and increasingly farm tracks. These roads generally represent more than 60% of the roadnet work in any country. According to Ministry Of Agriculture this value increases up to about 70% in Turkey and this shows the importance of recycling processes for Turkey (Fig.2.1.1)

2.1.1 In place recycling

2.1.1.1 Advantages of in place recycling

Recycling in-place eliminates the excavation of the existing road structure, the removal of the excavated material, the transport of the new raw materials, thus saving material resources, nowadays one of the most important demands everywhere.

No wounds are created in the landscape; quarries and landfills are kept to a minimum.(Fig.2.1.2)

A comparison of the conventional rehabilitation methods with the cold recycling process results in the substantial advantages in favor of cold recycling.

The excavation of the old surfacing requires an excavator and an appropriate fleet of transport lorries. This is where the initial costs are incurred. When loading, the excavator requires enough space to swing around without endangering the road traffic. The negative impact of the haul-away lorries on the road network should not be underestimated. More costs can be incurred owing to unforeseeable breakdowns of the transport vehicles. After the working level has been finished ,new material has to be transported to the site to replace a large proportion of the materials previously hauled away. This again entails a substantial amount of transportation and the laying of scarce raw materials.(Fig2.1.3)

The application possibilities described below relate exclusively to "cold recycling in place". The fast construction method of cold recycling involves the use of cement or bitumen or a combination of the two as a binder.(Fig.2.1.4)

2.1.1.2 Standard Machine Types

Several types of equipment are available for cold recycling process. As examples , existing types of Wirtgen Company , namely The RX 110,The 1000C-R and The 2100 DC-R are presented.(Wirtgen Company , 1992)

RX-110 (Figure2.1.5)design allows:

- The material to be cut
- The surface to be planed
- The material to be sized
- New material to be added
- All material to be mixed uniformly

The parts of RX 110 and their functions

As it is seen in figure 2.1.5

Dual bucket elevators: To elevate the milled material to the screen deck for sizing

Horizontal vibratory screen: Screens the material and discharges oversize material into the on board RAP crusher

On board rap sizing crusher: Reduces the oversize material and returns it to the roadway to be cycled through the system again

Front to rear material conveyor: Transfers sized material to the dual shaft pugmill

Conveyor mounted weigh bridge :Mounted in the conveyor, weighs the material for precise liquid addition.

Liquid additive pump system : Simply designed for reliability ,the additive system includes pump, filter, meter, and computer which takes the material weight and machine speed to determine liquid required.

Dual shaft pugmill: Accept material from the material conveyor ,accepts liquid additive for the pump via the spray bar and mixes the two vigorously to produce a full specification cold recycle material.

1000C-R AND 2100 DC-R

Below is the table (2.1.1)showing a comparison between 2100 DC-R and 1000 DC-R

Wirtgen Company machines which are most frequently used in cold recycling processes.

Table 2.1.1 Comparison Between The Cold Recycling Machines

	Working depth	Width	Cement	Emulsion	Cement and emulsion
2100 DC-R	300 mm	2000 mm	+	+	+
1000 C-R	100 mm	1000 mm	-	+	-

- **1000C-R**:Fields of application are the recycling of roadway edges, trench areas and smaller surfaces. This machine is mainly used for recycling work with bitumen emulsion. The cold recycling machine with an integrated spray unit, mixer and the screed is attached to the cold milling machine 1000 CR. (Fig.2.1.6)

- **2100DC-R**:Fields of application are large area rehabilitation projects for working depths down to 30 cm.

The 2 m. wide milling drum is fitted with the point attack cutting tools and is driven directly by the diesel engine by means of power bands through a clutch. This cold milling has the following advantages:

Public Convenience: Cold Milling can be done quickly with the minimum interruption to the traffic flow. And when the process is complete , the restored pavement can be opened to traffic immediately.

Safety and Cleanliness: The process generates no smokes or flame but small amount of dust can be seen which can be easily be controlled.

Versatility: The cold milling is not limited to interstate or primary highways. A wide range of planning machines makes the process affordable by cities and smaller communities.

The four crawler chains with their individually driven hydromotors guarantee high fraction.

With a sealing cap in the front plate or in the scraper blade of the drum unit the recycled material can either be loaded by the conveyor belts onto lorries or deposited in a heap between the rear crawlers.

An electronic automatic levelling system guarantees that the selected. working depth is maintained.(Fig.2.1.7)

•Gradation control beam

A gradation control beam is arranged directly in front of the milling drum revolving opposite to the working direction. It reliably prevents large lumps from being broken out at any milling depth.(Fig.2.1.8 Fig.2.1.9)

•Binder spray system

The integrated spray system automatically controls the supply of water and emulsion in line with the preselected quantities. (Fig.2.1.10)

This system offers the possibility both binder and water, supplied either from the integrated machine tanks or directly from a road tanker.
Operation is simple: The milling width milling depth material density and the desired amount of binder or water to be added are preselected.

A reliable micro processor control then automatically monitors the amounts added in percent by weight as a function of the advance speed. The values are shown on a display(Fig.2.1.11)

•Screed

Another economic solution is direct laying method using a various speed mounted on the 2100 DC-R. It guarantees flush laying on the recycled material even on sharp curves. The screed lays the milled material with the correct camber. The recycled material can also be laid with a straight cross fall using an adjustment facility. The height adjustable screw mounted in front of the screed spreads the material. The infinitely variable tamping and vibration frequency of the screed guarantees high precompaction. (Fig.2.1.12)

When it was stated above that the thickness of the bituminous layers play a subordinate role this means ,on one hand, that the cold recyclers can mill down to a depth of 30 cm. Anyway and, on the other hand that the bituminous layers are if material to an asphalt mixing plant for re-use in hot asphalt production. This therefore results in 100%recycling,too.(Wirtgen Company , 1992)

When establishing the milled depth it must be ensured that filter stability of a roadway is retained so that water which has penetrated the road structure from the side can also escape from the side or downwards.

Below are the operations of cold recycling processes with a cement , bitumen emulsion and combination of the both. Here is the chronological sequence:

2.1.1.3 Cold recycling With Cement

•Spreading of the cement

In order to achieve as uniform as possible a distribution of the cement in the milled material ,the cement should be laid with a cement spreader .The milling drums in our milling machines are designed so that they produce optimum mixing. However success should be assured by exploiting every possibility ,such as accurate distribution of the cement and the optimum mixing ,in order to achieve a substantial improvement in the load bearing capacity with the newly created , hydraulically bonded base course (Fig.2.1.13)

The required amount of cement must be ascertained in the qualification test. Experience has shown that the amount of cement required is between 3.5 and 4.5 % by weight. The data bank available at Wirtgen Company can be important aid .(Table.2.1.2)

Table.2.1.2 Depth of the fill of the cement to be laid as a function of the proposed amount to be added in %(Wirtgen Company , 1992)

Percentage of added cement	Max. Dry Density t/m³	necessary mass of cement in kg/m² Working depth 10 cm	20 cm	30 cm
2 %	2,1	4,2	8,4	12,6
	2,2	4,4	8,8	13,2
	2,3	4,6	9,2	13,8
3 %	2,1	6,3	12,6	18,9
	2,2	6,6	13,2	19,8
	2,3	6,9	13,8	20,7
4 %	2,1	8,4	16,8	25,2
	2,2	8,8	17,6	26,4
	2,3	9,2	18,4	27,6

•Milling and mixing with the Wirtgen cold recycler 2100 DC-R

During the milling and mixing process the in-situ material is homogeneously mixed with the spread cement and the water which is sprayed on by the microprocessor-controlled dosing unit. The recycled material leaves the milling machine through an opening in the scraper blade and is deposited as a windrow

•Laying of the milled material

Whether the recycled material should be laid with a grader or a finishing screed integrated in the milling machine should primarily depend on the appearance of the road. If the customer wants to achieve a change in the camber in the case of heavily structured road , laying with a grader is unavoidable. The advantage of the vario screed in terms of laying-accuracy and precompaction of the milled material is, of course very substantial.(Fig2.1.14)

•Compaction

Compaction is performed with rubber tyre rollers, smooth-wheeled rollers or combined and tandem vibratory rollers with an appropriately high service weight. (Fig.2.1.15)

As the method described here a generally involves a superstructure with a seal coating a bituminous course or a wearing course, it is imperative that the hydraulically bonded base course is notched when

(1) The average compressive strength of the material mixture exceeds 12 N/mm/mm in the qualification test.

(2) With entire depths of 20 cm. and more

(3) Under asphalt courses with a total thickness of less than 14 cm.(Wirtgen Company 1992)

This is not a superfluous demand but which is made in the ZTVT-StB 86(additional technical contractual terms and guideliness for base courses in road construction) to avoid reflective cracks in the asphalt layers.

The notches are spaced at between 2.5 and 5m notching can be performed by cutting with a joint cutter ,a vibrating plate with a notching blade or by producing microcracking.

2.1.1.4 Cold recycling with bitumen emulsion

When the cold recycling method is used with bitumen emulsion it is imperative first of all to perform a qualification test on the existing materials. The following parameters should be examined by an experienced laboratory. (Fig.2.1.16)

•Gradation

•Examination of binder

- compatibility of the emulsion
- Determination of max. density(Duriez Test)
- Test of the mechanical properties

Both an anionic and a cationic emulsion can be used as a binder. Cationic emulsions with a bitumen proportion of 60% are most frequently used.(Wirtgen Company Labarotory Tests , 1992)

When an anionic emulsion is used ,the water must first evaporate before the emulsion can be regarded as broken. Therefore ,base courses made with an anionic emulsion must be allowed to dry out.

With the cationic emulsion ,the breaking process is triggered by the chemical behaviour of the stone. The breaking time can be specified before production of the emulsion at the user's request. During breaking the water is repelled ,the finally dispersing binder combines to form a binder film and coates the material grains.

The working depth during cold recycling with bitumen emulsion should be about 12 cm. This empirical value was determined on many road tests in Germany and Europe(Asphalt Institute Manual series No:21 , 1983).No significant value has been recorded in our country as no road tests have been made in cold in place recycling process.

Opposite to the use of cement a roadway recycled with cationic emulsion can be opened to traffic without any reservations on completion of the compaction work and after the drainage of water.

This is a definite advantage if a thin bituminous layer is recycled with the crushed stone sub-base. The aqueous components of the emulsion can drain down into the crushed stone base course or drain away over the surface.

Most all road surfaces recycled with bitumen emulsion are given a bituminous wearing course as a sealing coating as a final operation. This method of construction will gain widespread use where the laying of hot mixed materials presents innumerable problems owing to long transport distances and the lack of an asphalt mixing plant.

2.1.1.5 Cold recycling with cement and bitumen emulsion

The third possibility of cold recycling is the use of cement together with a bituminous emulsion.

This method offers the advantage that the proportion of emulsion can be reduced. This contributes towards reducing the production costs as the prices of the emulsions are at present still above those of cement.

Another construction advantage is the reduction in the rigid nature of a cement bonded layer and an increase in elasticity(Fig 2.1.17).

2.1.1.6 Cold recycling of polluted materials

Another interesting possibility of the cold recycling process is its use in connection with polluted materials, generally tar.(Fig. 2.1.18)

The course made with tar ,for example, are treated in the same way as in cold recycling with bitumen emulsion .The emulsion coates the milled material and thus prevents leaching of the polluted materials. It is always laid as a base course which is always covered with other asphalt courses.

However, the polluted material can also be enveloped with emulsion during the milling process and the treated material taken away for interim storage or to be laid again directly at another site.

Roadways made with tar-coating binder are becoming old and ready for rehabilitation.

In the search for cost saving and practical methods, cold recycling will certainly be employed as a low cost and ecologically process for disposing of problematic materials.

2.1.2 Central place recycling

- **Reclaimed Materials**: Reclaimed materials for central plant cold mix recycling are obtained by ripping and crushing , or cold milling the old pavement. In the ripping and crushing operation, scarifiers or rippers are used to break up the asphalt pavement. Then it is loaded and hauled to a crushing and screening plant where the pieces of the broken pavement are reduced to acceptable limits.

Specialized cold milling or planning machines have been developed that can reclaim asphalt pavement to controlled depths. In the process the pavement is reduced to the desired max. particle size ; it is then hauled to the central plant. The reclaimed mix, reclaimed aggregate and any new aggregate should be proportioned separately.

The height of reclaimed asphalt pavement stockpiles should be limited to prevent the crushed materials from sticking together because of dead load and high air temperatures. For the same reason , construction equipment should not be permitted on the stock pile. One way to minimize both sticking and excessive moisture is to coordinate the crushing and mixing operations so that a large stockpile of crushed reclaimed asphalt pavement is unnecessary. Reclaimed untreated aggregate should stockpiled in the same manner as new aggregate.

- **Stationary plants :**Central plant mixing is generally accomplished away from the road site. However , the central plant usually consists only of a mixer and certain auxiliary equipment for feeding the asphalt , water , reclaimed asphalt pavement , and aggregate to the mixer. It is therefore readily transported and easily erected.

The asphalt and water pumps should be interlocked with the aggregate flow to produce a uniform mixture.

A stationary plant may be either a batch , drum , or a continuous type, although the latter is most often used for cold recycling.(Fig:2.1.19)

- **Mix preparation:** In batch-type plants , mixing is usually accomplished with a thin-shaft pugmill .Sized reclaimed asphalt pavement , reclaimed aggregate material and new aggregate (if required) are proportioned by weight with new asphalt and any needed mixing water before being fed into the pugmill. The batch is mixed and discharged into a haul truck before another batch is produced.

In continuous-mixing plants, the devices feeding the materials are interlocked to automatically maintain the correct proportions. Typically , automatic feeders measure and govern the flow of materials in relation to the output of a positive displacement asphalt metering pump. Because the asphalt is added to the mix on a volume basis , corrections must be made for the difference in volume according to temperature. As the proportioned materials move through the pugmill , the mixed material is discharged for subsequent hauling to the road site(Fig.2.1.20)

A commonly misunderstood aspect of plant-mixed emulsified asphalt is mixing time. Emulsion mixes usually require shorter mixing time than asphalt concrete mixes. The tendency is to overmix emulsified asphalt bases. This has the effect of scribbing the emulsified asphalt from the coarse aggregate particles. It also may result in the premature breaking of the emulsified asphalt , causing overly-stiff mixtures.

A less common problem is insufficient coating of the aggregate , caused by undermixing. Mixing times can be varied in a continuous pugmill plant by changing the arrangement of the paddles , by varying the height of the end gate , or by changing the location of the asphalt spray bar. With a drum mix plant , mixing time is controlled by varying the slope of the drum or by changing the location of the asphalt inlet pipe within the drum.

It should be noted that , with emulsified asphalt , regardless of the mixing method , 100 percent coating of the coarse aggregate particles is not always achieved , neither is necessary. Additional coating will occur as the mixture is manipulated through the spreading procedure and during rolling. Some aggregate types might be difficult to coat properly , but this fact should be evident at the mix design stage.

Mixing procedures should aim at achieving a uniform dispersion of the emulsified asphalt with a complete coating , of the finer aggregate fractions.

• **Aerating plant mix:** Mixtures that require aeration are generally deposited upon the roadbed in windrows.

Similar to the mixed in place materials , central plant recycled cold mixes gain stability as the water that has made the mix workable evaporates.

• **Spreading and compaction** If mixing moisture can be controlled accurately to all level not requiring aeration or if climatic conditions and aggregate gradation permit evaporation of moisture without aeration by manipulation , a conventional self-propelled asphalt paver may be used to replace recycled asphalt cold-mix.

The successful placement of cold mixes with conventional pavers requires the presence of sufficient fluids. Dry mixes tend to tear beneath the screed or strike off bar. If the mixture is too dry , the mix water content should be increased. When a self-propelled highway paver is used , heating the screed in attemps to eliminate this tearing does not help. It actually makes the mix less workable , since it serves to accelerate the drying process.

The mixture should be spread uniformly on the roadbed , beginning at the point farthest from the mixing plant. Hauling over freshly placed material should not be permitted except when required for completion of the work.

Spreading equipment such as jersey spreaders and towed spreaders are also used for cold recycling.

A jersey spreader is a front-wheeled gopper that is attached to the front end of a crawler or rubber tired tractor. The asphalt mixture is dumped into the hopper and the mixture falls directly to the road where it is spread and struck off a controlled thickness. To begin spreading the mixture at the specified depth the tractor should be driven onto blocks or boards equal to the depth of the uncompacted spread and placed so that the tractor will ride directly onto the newly placed material.

Towed type spreaders are attached to the rear of haul trucks. The asphalt cold mix is deposited into the hopper and falls directly to the surface being paved. As the truck moves forward , the mixture is struck off by a cutter bag , a blade , or by the screed.

The spreader should be towed at a uniform speed for any given setting of the screed or strike-off device. Variations in towing speed will vary spread thickness. Also frequent stopping and starting may allow settlement of the screed and result in a bump in the pavement surface.

2.1.3 Material studies

The preliminary examination are conducted before work commences. The scope varies depending on the job specifications. If the contact already specifies the working depth and the binder, preliminary examinations are confined to merely determining the material quality and homogeneity. Moreover areas may have to be established where additional material is to be laid(e.g. wheel ruts)

If it is necessary to compile rehabilitation concept, the following measures are recommended:

-Visual inspection of the road condition

- Determining the areas for possible adaptation of the transverse or longitudinal camber

- Ascertaining the existing structure of the road

-Quality test of the existing materials laid

-Determining the binders

-Determining the working depth.

The above action is described in more detail below:

The visual inspection is the fist measure to obtain a clear picture of the condition (cracks, material loss) and the route (edging, bridges underpasses) of the road. Records are made of important features to be observed during performance of the work.

In the event of severe lateral displacement of the road surface ,its causes must be established.

It is necessary to determine the areas for the necessary changes to the transverse or longitudinal camber in order to establish the need for additional quantities of minerals or milled material.

The existing structure is established by taking representative core samples distributed over the surface. The unbonded layers under the test cores are lifted out manually, the material of every unbonded layer must be removed separately. In order to obtain an adequate number of samples it is recommended to take at least two test cores per test site. After excavation the depth and the thickness of each layer is established.

The quality of the exiting materials is determine using the standardised test methods(grain-size determination analysis etc.) The sample material can be used for the qualification test.

The homogenity can be seen from the statistical evaluation of the results of all samples, assuming a representative distribution.

When the material characteristics are available it is possible to make a decision on which binder to use. Here some aspects are decisive, e.g:

* thickness of the course to be milled
* availability of the desired binder
* type of the material of the courses (bituminous ,unbonded or polluted materials)
* climatic zones or hydrological aspects (filter stability of subcourses)

Finally the milling depth is established, if necessary section by section.

Finally the milling depth is established, if necessary section by section.

2.1.4 Advantages of cold recycling:

The advantages of this technique can be summarized as follows:

- Savings by reusing the bitumen and the aggregates and energy savings by using a cold procedure.
- High structural strength, between that of grave-emulsion and hot asphalt
- Flexible paving technique, therefore
  - -no cracking
  - -thin course laying possible
- Possibility of not increasing the level of the pavements (important in cities)
- The ability to only treat one lane (esp. slow lanes)
- Immediately reopened to traffic
- Reduction in costs in relation to traditional solutions. An outline of the ecological and economic advantages of the cold recycling process.

Below is the table (2.1.3)showing comparisons between the conventional and cold recycling methods.

Table 2.1.3 Differences Between Methods

	Conventional Method	**Cold Recycling Method**
Excavator Transport	required	not required
Excavator for breaking up the road	required	not required
Lorries for taking away the material	required	not required
Landfill costs	very high	dispensed with
Lorries for bringing material to the site	required	only in isolated cases
Grader or crawler for laying the material	always required	only when no screed available
Compaction machinery	required	required
Duration of construction work	considerable	short
Additional burden on the road networks as a result of the road works	very high	minimal

2.2 Hot mix recycling process

Hot mix recycling is a process in which reclaimed asphalt pavement materials , reclaimed aggregate materials , or both are combined with new materials and/or recycling agents , and/or new aggregate , as necessary in a central plant to produce hot mix paving mixtures. The finished product meets all standard material specifications and construction requirements for the type of mixture being produced. Thus first the composition of the reclaimed asphalt pavement must be determined. This will include:

- Aggregate gradation
- Asphalt content

Then the gradation of the reclaimed aggregate materials (RAM-Removed pavement materials containing no reusable binding agent) , if any ,must be determined. This information is used to define the quantity of new asphalt cement that is needed , and the gradation and the quantity of additional aggregates. The aggregate and the asphalt in the reclaimed asphalt pavement have properties that must be evaluated separately. Therefore it is necessary to extract the aged asphalt from a representative sample of the reclaimed asphalt pavement.

a)Aggregate evaluation: A sieve analysis is performed on the aggregate portion of the reclaimed asphalt pavement sample to determine the gradation. Any deficiencies can be corrected by blending appropriate sieve fractions of new and/or reclaimed aggregate with reclaimed asphalt pavement aggregate.

b)Extraction: The purpose of the extraction is quantitative separation of the aggregate and asphalt

c)Asphalt evaluation: The asphalt content of the reclaimed asphalt pavement is determined on the basis weights of the extracted asphalt and aggregate .Its consistency then is determined on the basis of viscosity at 60 C. This determination is necessary to estimate the required amount and grade of asphalt to be used in the recycled mix design.

d)New asphalt: New low viscosity asphalt cement , added to the mixture of reclaimed asphalt pavement and new aggregate , serves two purposes.

•It increases the total asphalt content to meet the requirements of the mixture

•It blends with the aged asphalt in the reclaimed portion of the mixture to yield an asphalt meeting the desired specifications:

e)Recycling agents Recycling agents are organic materials with chemical and physical characteristics selected to rejuvenate hard and brittle aged binders and restore aged asphalt to desired specifications. In the hot mix recycling , additives are particularly applicable where the ratio of reclaimed to new material is high. The determination of the correct type and quantity of additive needs to take into account

2.2.1 Objectives of hot mix recycling

Hot mix recycling is a proven process that may be used to upgrade worn-out pavements. In the addition a major benefit is realized by adding asphalt to untreated granular material in the lower layers of the pavement structure and then placing the material back in the same thickness. This increase in the thickness of the layers that are asphalt bound increases the strength of the pavement structure thus increasing its load carrying capacity. By this means , existing composite structural sections can be converted to high quality thick-lift or full depth asphalt pavements(a full depth asphalt pavement is one in which asphalt mixtures are used for all courses above the subgrade or improved subgrade.)

On the basis of cost-effectiveness alone , hot mix recycling of existing pavements should be a major consideration in planning rehabilitation.

An important reason for recycling is the need to conserve natural resources. Economy , ecology and energy conservation are all served when asphalt and aggregate_the most frequently used pavement construction materials_ are reused to provide a strengthened and improved roadway.

2.2.2 In place recycling

The recycling is done by a recycling system which consists of four heavy duty:

- Heat
- Remove
- Reprocess
- Relay

As it is known asphalt pavement consists of a black sticky petrochemical substance known as bitumen and graded crushed stone called aggregates. To successfully remove and reprocess these materials they must be heated to liquify the asphalt oil , and remove moisture .But common problem in asphalt recycling is that the bitumen becomes overheated which results in reduced recycled pavement quality and excessive smoke emissions . To prevent this , different firms developed different types of machines.

ARTEC Company , specialized in hot recycling works developed the AR 2000.It offers heating system (The thermo Jet) which simultaneously applies high velocity hot air and low level infrared radiation to the road surface , a combination which has been demonstrated to heat pavement effectively without overheating.

• **Working Principle of the Thermo Jet System:** Thermo jet system heats air in a central combustion chamber as shown in fig(2.2.1) and then blows it onto the pavement surface at high velocity through of small outlets as shown in fig(2.2.2), Super heated stainless steel tubes , which carry the hot air provide the low level infrared radiation.

The AR 2000 heating system is a recirculating system which means fuel use is minimized and hot air is not wasted by escaping from around the edges of the heating bed. After the hot air is blown onto the pavement surface, it is vacuumed back into the combustion chamber where it is restored to optimum temperature and reused.

The AR 2000 Multi-Stage Recycling Process

•**Preheating** :In the first stage , two identical preheater units heat and soften the deteriorated asphalt surface.(Fig.2.2.3)

•**Hot milling**: In the second stage the Heater/Miller applies additional heat and then removes the softened pavement to the desired depth. The loosened material is then windrowed to the center of the lane.(Fig 2.2.4)

•**Heating and stirring**: The fourth machine in the train , the heater mixer incorporates strirring blades which continually agitate the loosened material during the application of heat. This unique post heating provides the following additional benefits:

1-Superior drying of recycled pavement materials
2-The most even heating to allow maximum temperature control

•**Mixing of the additives**: Once the recycled material processed by the heater mixer has attained the desired temperature, it moves up a conveyor into a twin shaft pugmill mixer as shown in fig(2.2.5).if required, virgin mix or coated aggregate may be added to the process in the front-mounted feed hopper. The pugmill chamber provides 15 to 30 seconds of through mixing to ensure uniformity of product.

Subsequent to recycling, the laydown and compaction processes are performed in a manner identical to those of conventional asphalt paying laydown Figure 2.2.6 and figure 2.2.7 are showing the general aspects of AR 2000 Super Recycler.

Engineering options

The ARTEC AR 2000 offers the pavement design engineer the ultimate flexibility in the mix design options. Whether simple rejuvenation with a recycling agent is required or complex asphalt mix/aggregate gradation modifications are desired, the AR 2000 provides the widest range of equipment capabilities.

The AR 2000 Super Recycler is capable of three basic in place recycling options with the following variations possible:

1)100% recycle: With or without rejuvenating additives
2)Remix:With new hot mix asphalt and/or rejuvenating agents added
3)Remix:With aggregate and rejuvenator or asphalt cement

100% Recycle

The asphalt surface can be 100% recycled (Artec 2000 International Cooperation, 1990)to a consistent and accurate depth of 50 mm in a single pass , provided the subgrade is sound and the existing mix design is acceptable. Preventative maintenance and surface rehabilitation are now more economical by recycling asphalt pavement that already contains high quality aggregate and asphalt cement.

Remix Options

The REMIX process is used when the analysis of the existing mix design indicates that improvements are needed to increase stability and strength or where the air voids must be increased to allow for the addition of a rejuvenator. Depending upon the condition of the existing asphalt cement, the rejuvenator is added at rates typically ranging between 25 to 75 litres per square meter at a recycling depth of 40 mm to 50 mm.

When a material is required it is thoroughly mixed with the hot recycled material and placed as a single layer homogeneous mixture. The new material can be either:

•a specified amount of virgin hot mix;or

•small quantities of crushed aggregates or sand

Recycling additives are highly recommended to maximize long term performance of the recycled asphalt material. These agents are designed to combine with the aged asphalt cement , restoring it to the consistency and quality of new asphalt cement with improved durability and ride quality. Below are some pavement defects and solutions to these defects by AR 2000 Super Recycler:

Defects migrating upward through conventional overlay. Pavement defects covered by conventional asphalt overlays migrate to the surface in a short time. The AR 2000

Cracking:

•Cracked material is removed remixed and relaid

•Flexibility restored by rejuvenating agents ;Additional thickness can be added to provide improved structural capacity (Fig.2.2.9)

Rutting:

•Rutted material is removed , remixed and relaid

•Mix design is modified to improve stability or correct low air voids

•Additional thickness can be added to improve structural capacity (Fig2.2.10)

Ravelling:

•Uncoated or stripped material is removed remixed and relaid

•Aggregates are recoated by remixing

•Under asphalted mixes can be corrected by adding new bitumen

•Anti-stripping agents can be added

(Fig2.2.11)

Bleeding:

•Material is removed ,remixed and re-laid

•Low bitumen content mixes are added to increase air voids

•Uncoated aggregates can be added to increase air voids

(Fig.2.2.12)

2.2.2.1 Benefits of Hot in Place Recycling

Cost Effective*:*

Single lane repair and reuse of existing materials offers over traditional methods of asphalt resurfacing

Conserves Non-Renewable Resources

Hot in place recycling conserves limited natural resources such as asphalt and aggregate supplies.

Motorist Safety And Convenience

Motorists do not have to contend with dangerous uneven pavements , nor with messy and slippery oiled surfaces. Congestion caused by heavy hauling trucks at the work site is generally reduced by over 90%

Minimizes Traffic Disruption:

Hot in place recycling operations are over 50 % shorter in length than conventional paving operations. This significantly reduces traffic delays and congestion. Traffic control requirements are significantly reduced.

Single Lane Repair:

A single traffic lane is often subjected to more stress and deterioration relative to adjacent surfaces. Paved shoulders are often overlaid unnecessarily and at considerable expense. Recycling eliminates the necessity to repave the entire road surface. Preventative maintenance and repair of isolated sections result in substantial savings.

Maintains Existing Grades

Existing grades and elevations at curbs , manholes and beneath bridges and highway overpasses are easily maintained.

Hot Bonding

Heat is applied to the underlying surface and to all joints providing superior bonding between the old and new surface. The welded bond eliminates the need for messy and unsafe oil-coated surfaces.

Lower Inspection and Engineering Costs

By reducing or eliminating the need for new sources of aggregate , crushers , asphalt plants , weigh scales ,pavement surface oiling and shouldering , the engineering and inspection costs are considerably reduced.

Improved Mix Design:

Remix alternatives allow for improvements to be made to the original mix design for a fraction of the cost of traditional methods.

2.2.3 Central Plant Recycling

All hot mix recycling of reclaimed asphalt pavements is done by the heat transfer method. Recycled mixtures can and have been successfully produced in both batch and drum-mix plants. But some plant modifications are required. A number of procedures have been developed. The objective of each is to heat and dry the reclaimed asphalt pavement without exposing it directly to the high temperature flame and combustion gases in the dryer. Without these changes recycled mixtures can not be produced economically and effected from the exhaust stack emissions.

Both batch plants and drum mix plants have been modified for the successful production and because of the variety of procedures involved , each of the plant types will be discussed separately.

2.2.3.1 BATCH PLANTS

There are five methods for using RAP in a batch plant. In all of these methods the virgin aggregate must be superheated. The superheated virgin aggregate heats the

RAP. Table 2.2.1 shows the temperature to which the virgin material must be heated in order to heat and dry the RAP. As the table shows higher moisture content in the RAP and higher percentages of RAP require proportionally higher temperatures in the virgin aggregate. And unless the RAP is extremely dry RAP percentages in excess of 40% connot be used.(Asphalt Institute Manual Series MS 20 ,.1981)

Superheating virgin aggregates to extremely high temperatures causes the dryer shell to run much hotter than usual. This can damage the drum. Fig(2.2.13) shows an aircooled dryer. It allows superheating virgin aggregate to higher temperatures without damaging the drum. But using such a dryer allows only slightly higher percentages of RAP to be used.

Method 1: Cold RAP is introduced into the boot of the hot elevator along with superheated virgin aggregate as shown in fig(2.2.14) .Together , they are screened and stored in all hot bins. As water evaporates from the RAP it creates steam , which is continually pulled off by the scavenge system in the batch tower. This method causes no emission problems. However only low RAP percentages should be used unless the screen cloth in the bottom deck exceeds 0.48mm. to 0.64mm. (3/16 to ¼ inch) .Running higher percentages with less than 3/16 inch cloth procedures a sticky composition that often "blinds " the screen.

Method 2: The batch tower must have fifth hot bin as shown in fig(2.2.15). Cold prescreened RAP can be introduced at the boot of the hot elevator along with prescreened , super heated aggregate. The elevator delivers the blended material directly to the fifth bin , by passing screens in the tower . This method gives optimum results and allows using up to 35 % RAP. It allows switching from RAP mixes to virgin mixes without emptying hot bins because the hot materials in the hot bins are not super heated.

2.2.3.2 Drum Mix Plants

Five basic types of drum-mix plants capable of running RAP are available today.:

- •Parallel flow mixer with a center inlet drum
- •Parallel flow dryer coater
- •Counter flow dryer and a continuous mixer
- •Counter flow drum mixer
- •Double barrel plant

Fig(2.2.16) shows a parallel flow mixer with a center inlet for RAP: These plants were effectively used for recycling in the '70s and '80s.(Asphalt Institute Manual Series , 1982). However , emission standards become restrictive and percentages of RAP increased , these plants had difficulty with complying with restrictions on visible emissions. The problem was caused by the production of steam that distilled light oil from the virgin liquid AC and RAP.

Fig(2.2.17) parallel flow dryer in which the hot gases and aggregate move in the same direction .It also had a mixer at the discharge end of the drum. These plants successfully increased the amount of RAP that could be used in a parallel flow drum mixer because the virgin liquid AC material was not exposed to the steam in the drying process . This eliminated steam distillation in the virgin asphalt. The drum mix coater could use 30 to 35% RAP without smoking compared to parallel flow mixers that could run only 25% without smoking . However as RAP percentages increased and emission standards become more restrictive neither of these parallel flow plants could meet more stringent standards.

Fig(2.2.18) shows a counter flow dryer and a continuous mixer . As it is seen the virgin aggregate enters the end where gases are discharged. Consequently the gases travel in one direction while the aggregate travels ýn opposite direction. This plans is capable of running 35 to 50% RAP depending on how much moisture is in the RAP.

Fig(2.2.19) shows a counter flow drum mixer. With this plant all of the new emission standards can be met. But this plant has disadvantages. It has high shell temperatures and a short mixing time for recycle and virgin materials. Moreover its combined burner and mixing area does not provide easy access for maintenance and adjustment. And as higher percentages of RAP are run the short melting and mixing area in the drum may not allow sufficient melting of the RAP , resulting in a non homogenous mixture.

Fig(2.2.20)shows the double barrel drum mixer plant. As it is seen virgin aggregates are dryed in the inner drum. They are superheated to 315°C-365°C(600-650 F) when running 50% recycle. After drying, the virgin aggregates drop through the wall of the inner drum into the outer drum . There it meets with the recycle material and the two are mixed. The super hot virgin aggregate melt the old asphalt in the recycle material and the old asphalt coates the virgin aggregates before fresh liquid asphalt is injected into the mix. Mixing time in this outer shell is ¾ to 1 minute. The mix time is long enough to produce a very homogenous high quality mix. With this design , 90% of the heat for melting and drying the recycle comes from the virgin aggregate .The other 10% comes from the heat conducted through the inner shell. The outer shell of the double barrel stays at approximately 49°C(120 F) at all times. All these factors produce a highly efficient mixer.

Any smoke or odor coming out of the mixing section is pulled back through holes (the holes that the virgin aggregate pass through into the outer shell) in the inner drum. The pollutants go directly into the flame of the burner where they are consumed. As a result the double barrel mixer enables an asphalt plant to run high production volumes in using up to 50 % RAP without polluting the atmosphere .Moreover virgin asphalt and recycle materials are not exposed to hot gases and steam produced by the drying virgin aggregates in the inner shell. So these gases and steam can not distill oils from these materials.

For any of these plants mentioned above to produce good mixes containing RAP , the RAP should be screened as shown in fig(4-2-21)Oversized material should be crushed and run back through the system. Including large chunks of RAP in the mix does not give adequate time for the heat to penetrate the material. As a result large chunks of RAP would not be melted adequately . Generally to make a good mix containing RAP , the RAP should be reduced to its original size. If the RAP consists of a combination of base binder and surface material , it should be reduced to the size of the virgin aggregate in the material being produced. If this is done an excellent recycle product equal or better than the virgin mix can be produced.

2.2.4 Advantage of hot mix recycling

•Hot mix recycling is a proven process that may be used to upgrade wornout pavements.

•Viscosity of the hardened bitumen can be restored to its original size.

•Improved rideability

•Significant structural improvements can be obtained with little or no change in thickness.

•Additional right of way is not needed.

•Frost susceptibility may be reduced.

•Existing mix deficiencies can be corrected

•Problems are few:

-Air quality problems at the plant site may arise if appropriate and available equipment is not used , or if too high a percentage of reclaimed asphalt pavement is specified for the recycled mixture.

CHAPTER THREE
LABORATORY TESTS

3.1 Hot Mix Recycling Method Used

In this part of the study hot mix recycling tests were performed with the RAP obtained the Ankara Street , an expressway passing along the Campus of Ege University in Bornova. Making use of the procedures given in "Bituminous Mixtures Laboratory Hand Book" , published by General Directorate of the State of Highways first the extraction test was performed on five different samples taken from the above mentioned road in order to determine the average asphalt content. After the determination of the asphalt content , sieve analysis tests were performed both on the aggregates that were obtained from the extraction test and on new aggregates to be added. According to the specifications related with the wearing course , it should be proved to use new aggregates in order to keep the gradation within the limits given in the specifications. In this study, the new aggregates were obtained from a quarry in Mugla. As required by the method of hot mix recycling method , specific gravity tests were performed on the new aggregate fractions as well as on the bitumen.

Finally Marshall Stability Test was performed on hot mix asphalt paving mixtures. The detailed explanation of the tests that were performed in laboratory is given below:

3.1.1.The Extraction Method (ASTM D2172)

As a first step a centrifuge extractor of 1500 gr. capacity is used in order to determine the content of bitumen in the old mixture. Centrifuge Method is performed on each of the sample. The steps of Centrifuge Method are as fallows:

1- The sample is placed into the extractor and is heated up to 150 °C in the oven for the grains to be separated easily.

2- The sample is weighted after cooling with the cartridge paper.

3- The sample is then placed in the container of the extractor with the cartridge paper. Trichlorethylene is the solvent that is most frequently used in this method.

4- The solvent (about 200ml.) is poured on to the sample through the fill point which is on the top of the container.

5- The assembly is left up to one hour to allow the solvent to take the bitumen into the solution drained from the extension tube.

6- The centrifuge process is started and carried out until the drainage from the extension tube is completed.

7- The centrifuge process is stopped and a further 200ml. of solvent (tricholorethylene) is added through the fill point , then the process is restarted. This process should be repeated at least twice until the solution is clear.

8- The sample with the cartridge paper are put into the 110°C oven for the evaporation of solvent left in the mixture.

9- The sample with the cartridge paper are again weighted after cooling. The difference between the weights gives the bitumen content of the sample.

3.1.2 The Sieve Analysis (ASTM C136-80)

The second step was to perform Sieve Analysis Test both on the aggregates obtained from the extraction test and the new aggregates.

The steps of the test are as follows:

1-Before starting the test , the aggregates should be washed separately with a soapy water and then should be put into the 110 °C oven for drying.
2-The aggregates are sieved starting with the 19mm.(3/4 inch) sieve. The other sieve types that are used in this process are as follows:

- 12.5mm.(1/2 inch)
- 9.5mm.(3/8 inch)
- 4.75mm.(No 4)
- 2.0mm(No 10)
- 0.425mm.(No 40)
- 0.180mm.(No 80)
- 0.075mm.(No 200)

3-The cumulative weights retained on each sieve are recorded.

3.1.3 Specific Gravity and Water Absorption of Aggregate Fractions and Bitumen

As required by the method of hot mix recycling design , the following tests were performed on the new aggregates fractions:

a)Bulk Specific Gravity of the Coarse Aggregate and Water Absorption (ASTM C 127-80)

This test is applied on the aggregates retained on 4.75mm. (No:4) sieve. The steps related with this test are as follows:
1-1500 gr. of aggregates. are soaked in water bath for 24 hours. Then they are taken out and dried with a clean cloth. After drying they are weighted and recorded as saturated surface dry weight.(B)
2-The aggregates are weighted in water.(C)
3-The aggregates are placed into 110°C oven for drying , and weighted in air.(A)

Bulk specific gravity(Gk)=A/(B-C)

b)Bulk Specific Gravity and Water Absorption of the Fine Aggregate (ASTM C 128-79)

The test is applied on the aggregates passing 2,75mm.(No:4) sieve and retained on 0.075 mm.(No200) sieve. A 500 ml. picnometer is needed for this purpose. The steps of this test are as follows:

1-The picnometer is weighted.(A)

2-The picnometer is filled with distilled water and weighted.(B)

3-Saturated surface dry aggregates of 500 gr. are poured into the picnometer and weighted.(C)

4-Water is added on the aggregate filled picnometer until the level of water is over the level of the aggregate. It is then shaken for 20 min. until no airbubbles are seen in the picnometer. The picnometer is weighted after it has been heated in the 25°C water bath.

5-Fine aggregates are taken out of the picnometer and put into 110°C oven for drying and then are weighted.(E)

Bulk specific gravity (Gi)=E/(B+C-A-D)

c)Bulk Specific Gravity of the Filler

The test is applied on the aggregates passing 0.075mm. (No 200) sieve. A picnometer of 100 ml. is needed for this purpose. Below are the steps of this test:

1-The picnometer is weighted.(A)

2-The picnometer is filled with distilled water and placed in the 25°C water bath for 60 min. Then it is taken out and weighted.(B)

3-Before the filler has been placed into the 1/3 of the picnometer it is dried in the 110°C oven. The picnometer with filler is then weighted.(C)

4-Water is added to the vacuumed picnometer then heated in the 25°C water bath for 60 min. Then it is weighted.(D)

Bulk specific gravity of the filler (Gf)=(C-A)/((B-A)_(D-C))

According to the results of the specific gravity tests. Bulk Specific gravity of the aggregate mixture can be calculates as :

Gsb=100/((%K/Gk)+(%I/Gi)+(%F/Gf)).In this formula:
%K= The percentage of the coarse aggregate
%I= The percentage of the fine aggregate
%F= The percentage of the filller
Gk= Bulk specific gravity of the coarse aggregate
Gi= Bulk specific gravity of the fine aggregate
Gf= Bulk specific gravity of the filler

d)Specific Gravity of the Bitumen

A picnometer of 25 ml is needed for this test. The steps related to this test are as follows:

1-The Picnometer is weighted.(A)
2-The picnometer is filled with distilled water and heated in the water bath to a temperature of 25°C for 40 min.. It is then taken out and weighted.(B)
3-The picnometer is then approximately half filled with bitumen after it has been slightly heated. Then it is weighted.(C)
4-Water is added to the picnometer with bitumen and heated in the water bath to a temperature of 25°C then it is weighted.(D)

Specific Gravity of the Bitumen Gb=(C-A)/((B-A)-(D-C))

e) Effective Specific Gravity of the Aggregate Mixture

A picnometer of 4000 ml. is used for this test According to this test:

1-Aggregates are prepared according to the mix gradation specifications , heated and are mixed with bitumen.

2-They are placed into the picnometer and weighted.(C)

3- Water is then added to the vacuumed picnometer and placed in the 25°C water bath. It is weighted.(D)

Maximum Theoretical Specific Weight Dt=(C-A)/((C-A)-(D-B)) ; where

A= Weight of the picnometer

B= Weight of the picnometer filled with water

Effective Specific Gravity Gef=100/((100+Wa)/Dt-(Wa/Gb)) ; where

Wa= Content of the bitumen in the mixture

Gb= Specific gravity of the bitumen

The results of these tests were be used in the calculation of Marshall Stability Test values.

3.1.4.Calculation of the additional bitumen in the mix

According to the information given in Bituminous Mixtures Laboratory Handbook , published by General Directorate of the State of Highways , the bitumen content needed for the mix gradation of RAP and the new aggregate can be calculated by the following formulas:

Pc=0.035a+0.045b+X+F

Pr=Pc-(Pa*Pp) where;

a=The percentage of the aggregate that retained on 2.0mm.(No 8) sieve.

X=0.15c (The percentage of the aggregate passing 0.075mm.(No 200) sieve is between 11% and15%

X=0.18c (The percentage of the aggregate passing 0.075mm.(No 200) sieve is between 6% and10%

X=0.20c (The percentage of the aggregate passing 0.075mm.(No 200) sieve.

c=The percentage of the aggregate passing 0.075mm.(No 200) sieve.

F=0%-2% (a coefficient chosen according to the absorption of the material.

Pc=The total bitumen content in the mixture.

Pa=The bitumen content in the extracted asphalt.

Pp=The content of the extracted asphalt in the mixture.

Pr=The content of the new bitumen that is to be added in the mixture.

3.1.5 Marshall Mix Design Method

This is the method used in Turkey to design hot mix asphalt paving mixtures. The principles of Marshall Method are density -voids analysis and stability flow test. The aggregates that are used in this design must meet the requirements of the project specifications. Marshall Test E Machine (ASTM D1559) is used in this test.

A hot mix design were performed using six different asphalt contents,(Three test specimens were prepared for each asphalt content) which were increased by 0.5%.The steps related to mix design are as follows:

1-Mineral Filler and aggregates are heated in an oven to a temperature of 180-190°C

2-Asphalt cement is heated in a pouring can to a temperature of 120°C.

3-Aggregate and asphalt cement are mixed with a mixer. The temperature of the prepared mixture should not be less than 110°C.

4-After the heating operation of the aggregates the compaction hammer as well as the compaction molds are cleaned and heated to a temperature of 150°C.

5-The filter paper is inserted into the bottom of the mold to prevent adhesion between the mixture and the mold.

6-The hot mix is introduced into the mold. Seventy five blows are used for compaction depending on the amount of the tire inflation pressure used for the traffic design.

7-After the specimens have been removed from the mold they are alowed to cool to room temperature.

8-They are weighted in air and water for the determination of density.

9-They are then placed into the 60°C water bath for 20 min. to 30 min.

10-After the removal of the test specimens from the water bath , they are placed in the testing head. Compressive testing load is applied on the specimens until the failure occurs. The point of failure corresponds to the Marshall Stability of the specimen.

3.2 The Results of the Laboratory Tests

Taking into the consideration the explanations given in section 3.1 , sieve analysis was performed on five different examples. Also extraction test was performed on the same samples to determine the bitumen content. The results obtained were presented in Table 3.2.1-3.2.11.

Table 3.2.1 Sieve Analysis Results:SampleNo:1

Sieve No	Cumulative Wt. Retained (gr.)	% Retained	% Passing
½ INCH	80	19	81
3/8 INCH	118.7	28	72
NO.4	208	50	50
NO.10	286.7	68	32
NO.40	352.1	84	16
NO.80	382	91	9
NO.200	397.1	95	5

Initial dry weight:420gr.

Table 3.2.2 Sieve Analysis Results:SampleNo:2

Sieve No	**Cumulative Wt. Retained(gr)**	**% Retained**	**% Passing**
½ INCH	80	19	81
3/8 INCH	118.7	28	72
NO.4	208	50	50
NO.10	286.7	68	32
NO.40	352.1	84	16
NO.80	382	91	9
NO.200	397.1	95	5

Initial dry weight:447,5gr.

Table 3.2.3 Sieve Analysis Results:SampleNo:3

Sieve No	**Cumulative Wt. Retained(gr)**	**% Retained**	**% Passing**
½ INCH	60	15	85
3/8 INCH	110	28	72
NO.4	189.4	48	52
NO.10	255.8	65	35
NO.40	326.5	83	17
NO.80	354.5	89	11
NO.200	370.9	94	6

Initial dry Weight:396.2gr.

Table 3.2.4 Sieve Analysis Results:SampleNo:4

Sieve No	**Cumulative Wt. Retained(gr)**	**% Retained**	**% Passing**
½ INCH	74.8	17	83
3/8 INCH	128.1	29	71
NO.4	218.2	49	51
NO.10	293.1	66	44
NO.40	370.4	84	26
NO.80	400.7	91	9
NO.200	414.2	94	6

Initial Dry weight:442gr.

Table 3.2.5 Sieve Analysis Results:SampleNo:5

Sieve No	**Cumulative Wt. Retained(gr)**	**% Retained**	**% Passing**
½ INCH	68.6	16	84
3/8 INCH	112.2	26	74
NO.4	195.1	46	54
NO.10	277.7	65	35
NO.40	355.4	83	17
NO.80	388.1	91	9
NO.200	402.1	94	6

Initial Dry weight:428.9

Table 3.2.6 gives the average values of the sieve analysis of five examples:

Table 3.2.6 Average Values of the Sieve Analysis Tests

Sieve no	**Cumulative wt. Retained(gr)**	**% Retained**	**% Passing**
¾ INCH	—	0	100.0
½ INCH	—	17.2	82.8
3/8 INCH	—	27.8	72.2
No.4	—	50.0	50.0
NO.10	—	66.4	33.6
NO.40	—	83.4	16.6
NO.80	—	91.0	9.0
NO.200	—	94.0	6.0

Table 3.2.7 Extraction Test Values:Sample No:1

A	Container	
B	Container+Cartridge paper,gr.	395.5
C	Container+Cartridge paper+material,gr	842.1
D	Container+Cartridge paper+Material(Removed bitumen),gr	820.0
E=C-D	Weight of the bitumen,gr	22.1
F=D-B	Weight of the material(Removed bitumen)	424.5
E/F*100	Bitumen Percentage	5.2

Table 3.2.8 Extraction Test Values:SampleNo:2

A	Container	
B	Container+Cartridge paper,gr.	387.7
C	Container+Cartridge paper+material,gr	859.5
D	Container+Cartridge paper+Material(Removed bitumen),gr	835.2
E=C-D	Weight of the bitumen,gr	24.3
F=D-B	Weight of the material(Removed bitumen)	447.5
E/F*100	Bitumen Percentage	5.01

Table 3.2.9 Extraction Test Values:Sample No:3

A	Container	
B	Container+Cartridge paper,gr.	394.7
C	Container+Cartridge paper+material,gr	810.3
D	Container+Cartridge paper+Material(Removed bitumen),gr	790.9
E=C-D	Weight of the bitumen,gr	20.0
F=D-B	Weight of the material(Removed bitumen)	396.2
E/F*100	Bitumen Percentage	5.04

Table 3.2.10 Extraction Test Values:Sample No:4

A	Container	
B	Container+Cartridge paper,gr.	388.2
C	Container+Cartridge paper+material,gr	855.9
D	Container+Cartridge paper+Material(Removed bitumen),gr	830.2
E=C-D	Weight of the bitumen,gr	25.7
F=D-B	Weight of the material(Removed bitumen)	442.0
E/F*100	Bitumen Percentage	5.81

Table 3.2.11 Extraction Test Values:Sample No:5

A	Container	
B	Container+Cartridge paper,gr.	395.1
C	Container+Cartridge paper+material,gr	845.8
D	Container+Cartridge paper+Material(Removed bitumen),gr	824.0
E=C-D	Weight of the bitumen,gr	21.8
F=D-B	Weight of the material(Removed bitumen)	428.9
E/F*100	Bitumen Percentage	5.08

The average bitumen content=(5.2+5.01+5.04+5.81+5.08)/5=5.2%.This value will be used in the calculation of the new bitumen content that will be added in the mixture.

The results of the specific gravity tests of the new aggregates and the bitumen are given in Table 3.2.12-3.2.16.

Table 3.2.12 Specific Gravity of Coarse Aggregate &Absorption Percentage

A	**Dry Weight of the Sample,gr.**	1918
B	**Saturated Surface Dry Weight of the Sample(in air),gr.**	1927
C	**Saturated Surface Dry Weight of the Sample(in water),gr.**	1218
A/(A-C)	**Apparent Specific Gravity**	2.74
A/(B-C)	**Bulk Specific Gravity,Gk**	2.705
(B-A)*100/A	**% Absorpion**	0.4

Table 3.2.13 Specific Gravity of Fine Aggregate & Absorption Percentage

A	Weight of the Picnometer,gr.	190.1
B	Weight of the Picnometer+water	819.8
C	Weight of the Picnometer+Saturated Surface Dry Weight of the Sample	690.1
D	Weight of the Picnometer+Sample+Water	1133.2
E	Dry weight of the Sample	498.0
E/(B+E-D)	Apparent Specific Gravity	2.698
E/(B+C-A-D)	Bulk Specific Gravity,Gi	2.698
(C-A-E)/E	%Absorption	0.4

Table 3.2.14 Specific Gravity of the Filler

A	Weight of the Picnometer,gr.	114.0
B	Weight of the Picnometer+water	363.60
C	Weight of the Picnometer+ Dry Weight of the Sample	214.0
D	Weight of the Picnometer+Sample+Water	427.5
(C-A)/((B-A)-(D-C))	Bulk Specific Gravity,Gf	2.747

Table 3.2.15 Specific Gravity of the Bitumen

A	Weight of the Picnometer,gr.	22.50
B	Weight of the Picnometer+water	79.00
C	Weight of the Picnometer filled with asphalt,gr	45.9
D	Weight of the Picnometer filled with asphalt+water ,gr	79.1
(C-A)/((B-A)-(D-C))	Bulk Specific Gravity,Gf	1.03

Table 3.2.16 Effective Specific Gravity of the Aggregate Mixture

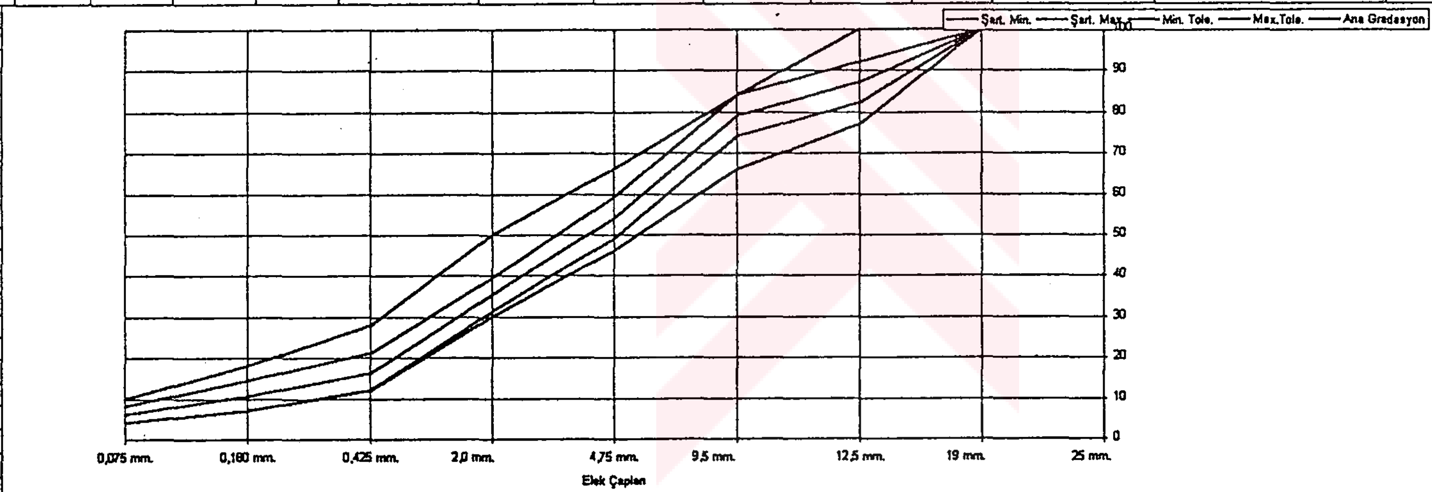
A	Weight of the picnometer,gr	
B	Weight of the picnometer+water,gr	503
C	Weight of the picnometer+uncompacted bituminous mixture,gr	3056
D	Weight of the uncompacted bit.mix.filled picnometer+water,gr	3779.5
Dt=(C-A)/((C-A)-(D-B))	Max. Theoretical Specific Weight	2.528
Wa	Bitumen Content	5.0
Gb	Specific gravity of the Bitumen	1.03
Gef=100/((100+Wa)/Dt-(Wa/Gb))	Effective Specific gravity	2.73

The Grain Size Distribution of the new aggregate is presented in Table 3.2.17.

TABLE 3.2.17 GRAIN SIZE DISTRIBUTION OF NEW AGGREGATE

SIEVE ANALYSIS

Mix ratios			22	28	50									
Sample			3/4"-3/	/8"-No	No4 - 0		WEARİNG COURSE TYPE 2							
									Tolerances					
Sieves		(Inches	% Pass	% Pass	% Pass	ain Gradatio	Spec. Min.	Spec. Max	Min. Tole.	Max.Tole	SIEVES	Main Gradation	Weight Retained (gr.)	Cummulative (gr.)
25 mm.	:	(1,0")	100	100	100	100,0	100,0	100	100	100	25 mm	100,0	0,0	0,0
19 mm.	:	(3/4"	97	100	100	99,3	100,0	100	100	100	19 mm	99,3	7,6	7,6
12,5 m	:	(1/2"	14	100	100	81,1	77,0	100	82	92,1	12,5 m	81,1	210,0	217,6
9,5 mm	:	(3/8"	1	78	100	72,1	66,0	84	74	84,0	9,5 m	72,1	103,7	321,3
4,75 m	:	(No 4)	0,4	8	98	51,1	46,0	66	49	58,9	4,75 m	51,1	240,7	562,0
2,0 mm	:	(No 1	0,4	0,7	78	39,4	30,0	50	31	39,4	2,0 m	39,4		
0,425	:	(No 4	0,3	0,3	32	18,2	12,0	28	12	21,1	0,425	18,2	588,0	1150,0
0,180	:	(No 8	0,3	0,3	23	11,8	7,0	18	7,0	14,5	0,180	11,8		
0,075	:	(No 2	0,2	0,2	18	8,3	4,0	10	4,1	8,1	0,075	8,3		



In the case of batch type plants hot mix recycling method allows using up to 35% RAP. Taking into consideration this value , firstly 30% of the old pavement was used for performing hot mix design. The mix gradation (30% of the RAP +70% of the new aggregate) must meet the requirements of the specifications related to the wearing course construction. Table 3.2.18 and Table 3.2.19 give the mix gradation and the limits of the specifications.

Table:3.2.18 Mix Gradation with 30% RAP and Specifications

Sieve Sizes	R.A.P.(%30)	New Aggregate(%70)	Mix Gradation	Specifications
1 inch	100	100	100	100
¾ inch	100	99.3	99.5	100
½ inch	82.8	81.1	81.6	77-100
3/8 inch	72.2	72.1	72.1	66-84
No 4	50.0	51.1	50.8	46-66
No 8	36.4	42.2	40.5	
No 10	33.6	39.4	37.7	30-50
No 50	15.1	16.2	15.9	
No 80	9.0	11.8	11.0	7-18
No 200	6.0	8.3	7.6	4-10

Table:3.2.19 Mix Gradation with 20% RAP and Specifications

Sieve Sizes	R.A.P.(%20)	New Aggregate(%80)	Mix Gradation	Specifications
1 inch	100	100	100	100
¾ inch	100	99.3	99.5	100
½ inch	82.8	81.1	81.5	77-100
3/8 inch	72.2	72.1	72.1	66-84
No 4	50.0	51.1	50.9	46-66
No 8	36.4	42.2	41.0	
No 10	33.6	39.4	38.2	30-50
No 50	15.1	16.2	16.0	
No 80	9.0	11.8	11.2	7-18
No 200	6.0	8.3	7.8	4-10

By using the results of the experiments, the content of bitumen is calculated by the formulas given in section 3.1.4.

Pc=0.035a+0.045b+0.18 c+F

According to the table 3.2.18 a=59.5%

b=32.9%

c=7.6%

Pc=0.035*59.5+0.045*32.9+0.18*7.6+1

Pc=6.08% .This value is the bitumen content in the total mixture.

Pr=Pc-(Pa*Pp) where Pc=6.08%

Pa=5.2%(The average bitumen content in the old pavement)

Pp=0.3(30% of the RAP is used)

Pr=6.08-(5.2*0.3)

Pr=4.52%. This value is the content of the new bitumen to be added in the mix design.

So according to the explanations given in section 3.1.5 Marshall Specimens will be prepared by mixing 30% of reclaimed asphalt pavement and 70% of new aggregate together with 60/70 penetration bitumen with the bitumen contents of 3.52% , 4.02% , 4.52% , 5.02% and 5.52%.Table 3.2.20 shows the Marshall Stability Test Results with 30% of RAP. The figures relating to this test is given in figure 3.2.1. a-b-c-d-e-f.

TABLE 3.2.28 MARSHALL STABILITY TEST RESULTS

Marshall Stability

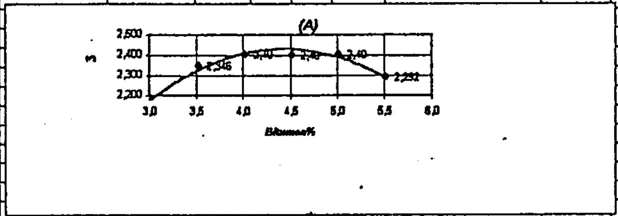
Pavement Ty: Wearing Course

No.of Blows : 75+75

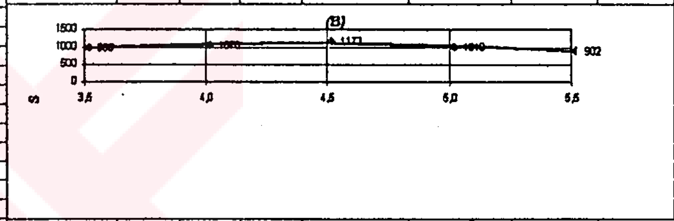
Briquette				eigh	of the	Briqutte		Weight in air(gr	Weight in Water(gr)	Sat.Sur. Dry Weight(gr)	Volume (cm3)	Bulk Spc.Weight	Max. Teo. Spc.Wght.	Voids (%)	V M A (%)	Voids Filled with Asp(%)	Flow(mm)	Stability (kg)	Corr Factor	Corr Stb.(kg)
No	Wa	Wb(%)	Gr.		2	3	Avr.	A	C	B	V	Dp	Dt	Vh		Vf				
1				62,6	63	63	62,6	1171,0	675,0	1178,0	504,0	2,323					2,7	965,6	1,023	988
2	3,52	3,40	40,48	61,7	62	62	61,67	1180,0	690,2	1183,5	493,3	2,392					3,4	975,2	1,046	1020
3				62,6	63	63	62,57	1171,0	675,0	1179,0	504,0	2,323					2,7	965,6	1,023	988
												2,346	2,573	8,80	15,73	44,08	2,9			999
4				61,7	62	62	61,73	1191,0	700,2	1195,0	494,8	2,407					3,8	959,1	1,046	1003
5	4,02	3,86	46,23	61,1	61	61	61,23	1186,0	697,5	1189,0	491,5	2,413					4,3	1037,7	1,062	1102
6				61,5	61	62	61,47	1190,5	697,5	1195,0	497,5	2,393					4,5	1049,1	1,053	1105
												2,404	2,554	5,87	14,06	58,28	4,2			1070
7				62	62	62	62,1	1191,0	706,1	1204,5	498,4	2,390					4,1	1099,7	1,068	1174
8	4,52	4,32	51,98	61,6	62	62	61,8	1198,5	702,5	1200,0	497,5	2,408					5,0	1130,1	1,056	1193
9				62,1	62	62	62,13	1198,0	702,5	1201,0	498,5	2,403					5,8	1100,8	1,046	1151
												2,401	2,536	5,34	14,60	63,40	4,9			1173
10				60,9	61	61	61,03	1190,5	697,3	1192,0	494,7	2,407					6,2	965,6	1,046	1010
11	5,02	4,78	57,73	61,3	61	62	61,4	1200,0	704,5	1203,4	498,9	2,405					7,9	987,9	1,062	1049
12				61,6	62	62	61,67	1200,0	704,4	1204,5	500,1	2,400					5,7	911,2	1,065	970
												2,404	2,519	4,56	14,90	69,40	6,8			1010
13				61,2	62	62	61,7	1189,5	671,9	1190,0	518,1	2,296					5,6	819,8	1,046	858
14	5,52	5,23	63,48	61,3	61	61	61,23	1182,5	666,9	1184,0	517,1	2,287					5,3	852,6	1,062	905
15				61,1	61	61	61,17	1186,0	670,0	1187,0	517,0	2,294					5,6	886,6	1,065	944
												2,292	2,501	8,36	19,23	56,51	5,5			902
16																				
17																				
18																				
19																				
20																				
21																				

Specific Gravity of the Bitumen(Gb)	1,029	%Coarse Aggr.(K%)	49,2	Bulk Spc. Gr. of the Coarse Aggr(Gk)	2,706
Penetration of the Bitumen=	60/70	%Fine Aggr.(I%)	43,2	Bulk Spc. Gr. of the Cos the Fine Aggr (Gi)	2,664
Bitumen Absorption of the Aggr.(P	0,371	%Filler(F%)	7,6	Bulk Spc. Gr. of the Filler (Gf)	2,732
Effective Spc.Gr. of the Agg.Mix.(Ge	2,716	Bulk Spc.Gr. Of the Agg.Mix(Gsb)=	2,690	Aggr. Content in the Briquette(gr.)	1150

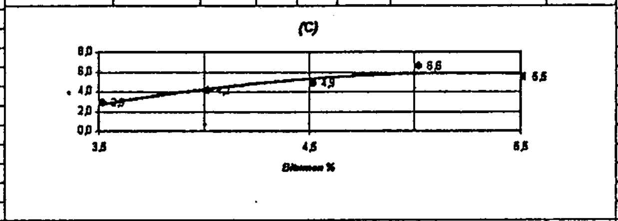
Bitumen %	3,5	4,0	4,5	5,0	5,5	0,0	0,0
Density	2,346	2,40	2,40	2,40	2,292	0,000	0,000



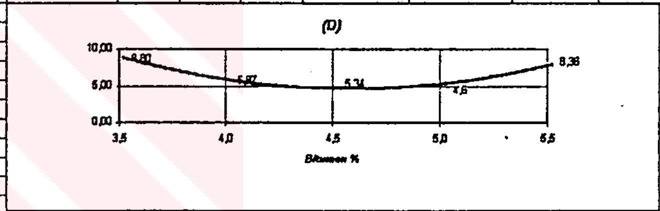
Bitumen%	3,5	4,0	4,5	5,0	5,5	0,0	0,0
Stability,kg	999	1070	1173	1010	902	0	0



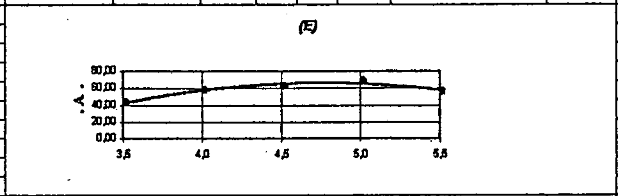
Bitumen %	3,5	4,0	4,5	5,0	5,5	0,0	0,0
Flow	2,9	4,2	4,9	6,6	5,5	0,0	0,0



Bitumen %	3,5	4,0	4,5	5,0	5,5	0,0	0,0
Voids %	8,80	5,87	5,34	4,8	8,36	0,00	0,00



Bitumen %	3,5	4,0	4,5	5,0	5,5	0,0	0,0
Voids Fll.With Asp.	44,08	58,3	63,4	69,4	58,51	0,00	0,00



Bitumen %	3	3,5	4	4,5	5	5,5	6
V.M.A %	15,73	14,06	14,60	14,90	19,23	0,00	0,00

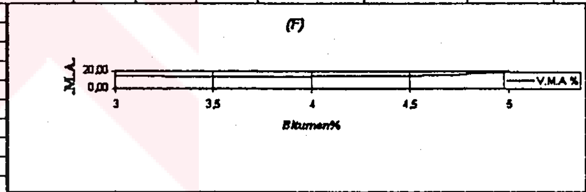


FIGURE 3.2.1 MARHALL TEST GRAPHICS

The following data is obtained from the figure 3.2.1:

•Asphalt content at maximum stability=4.65%

•Asphalt content at maximum density=4.55%

•Asphalt content providing 4%voids in the total mix=4.65%

•Asphalt content providing the maximum value of voids filled with asphalt=4.9%

Optimum asphalt content=(4.65+4.55+4.65+4.9)/4=4.70%

From the figure related to the stability vs. bitumen , stability value corresponding to 4.70% asphalt content is 1107 kg.

The same test was repeated using the 20% of the reclaimed asphalt pavement with the same penetration bitumen. Firstly the content of the bitumen is calculated.

Pc=0.035a+0.045b+0.180c+F

According to the Table 3.2.19. a=59

b=33.2

c=7.8

F=1

Pc=0.035*59+0.045*33.2+0.180*7.8+1

Pc=6.1%. This value is the content of the bitumen in the total mix.

Pr=Pc-(Pa*Pp) Where Pc=6.1%

Pa=5.2%

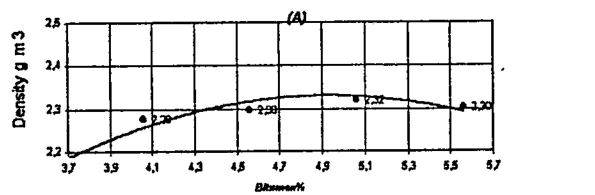
Pp=0.2(20% of the RAP is used)

Pr=6.1-(5.2*0.2)

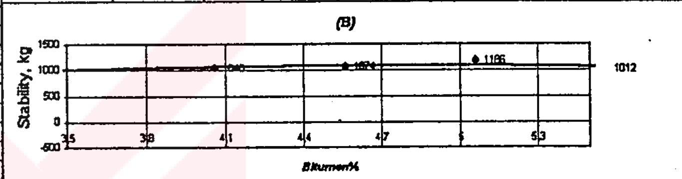
Pr=5.06%

So Marshall specimens were be prepared with the bitumen contents of 4.06% , 4.56% , 5.06% and 5.56

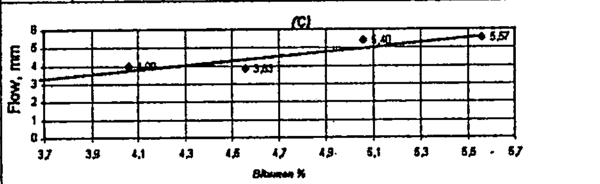
Bitumen	4,1	4,6	5,1	5,6	0,0	0,0	0,0
Density g	2,277	2,30	2,32	2,30	0,000	0,000	0,000



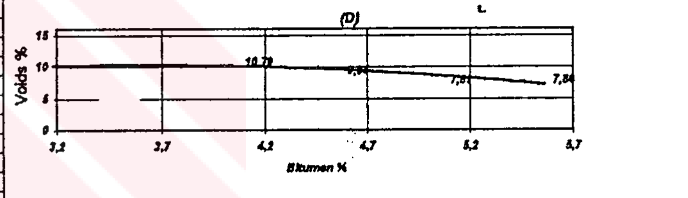
Bitumen%	4,1	4,6	5,1	5,6	0,0	0,0	0,0
Stability,kg	1048	1074	1186	1012	0	0	0



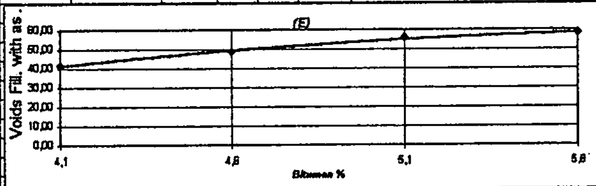
Bitumen	4,1	4,6	5,1	5,6	0,0	0,0	0,0
Flow,mm	4,0	3,8	5,4	5,6	0,0	0,0	0,0



Bitumen%	4,1	4,6	5,1	5,6	0,0	0,0	0,0
Voids %	10,79	9,35	7,81	7,9	0,00	0,00	0,00



Bitumen	4,1	4,6	5,1	5,6	0,0	0,0	0,0
Voids Fill With	41,85	48,7	56,1	58,1	0,00	0,00	0,00



Bitumen%	4,1	4,6	5,1	5,6	0,0	0,0	8
V.M.A	18,56	18,21	17,80	18,79	0,00	0,00	0,00

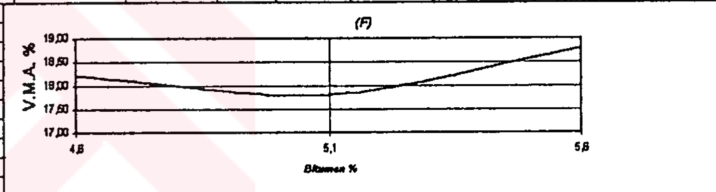


FIGURE 3.2.2 MARSHALL TEST GRAPHICS

TABLE 3.2.21 MARSHALL STABILITY TEST RESULTS

Marshall Stability

Pavement Typ	Wearing Course																			
No.of Blows	: 75+75																			
Briquette				eigh of the Briqutte				Weight in air(gr)	Weight in Water (gr)	Sat.Sur. Dry Weight (gr)	Volume (cm3)	Bulk Spc.Weight	Max. Teo. Spc.Wght.	Voids (%)	V M A (%)	Voids Filled with Asp(%)	Flow(mm)	Stability (kg)	Corr Factor	Corr Stb.(kg)
No	Wa	Wb(%)	Gr.		2	3	Avr.	A	C	B	V	Dp	Dt	Vh		Vf				
1				61,7	61	61	61,2	1180,0	665,5	1184,0	518,5	2,278					4,1	1004,7	1,062	1067
2	4,08	3,90	46,69	61,5	62	62	61,6	1184,5	668,5	1188,0	519,5	2,280					3,8	1000,0	1,049	1049
3				61,1	61	61	61,13	1185,0	669,3	1190,0	520,7	2,276					4,1	966,3	1,065	1029
												2,277	2,553	10,79	18,56	41,85	4,0			1048
4				61,3	61	62	61,53	1186,5	672,1	1189,0	516,9	2,295					3,7	959,1	1,053	1010
5	4,56	4,36	52,44	61,2	61	61	61,2	1188,0	674,7	1190,0	515,3	2,305					3,8	1037,7	1,062	1102
6				61,4	61	61	61,3	1186,0	672,7	1190,0	517,3	2,293					4,0	1049,1	1,059	1111
												2,298	2,535	9,35	18,21	48,68	3,8			1074
7				60,5	61	61	60,67	1185,0	675,8	1189,0	513,2	2,309					5,1	1099,7	1,078	1185
8	5,06	4,82	58,19	61,1	61	61	61,13	1194,5	684,6	1197,0	512,4	2,331					5,3	1130,1	1,065	1204
9				61,2	61	61	61,2	1199,0	687,5	1204,0	516,5	2,321					5,8	1100,8	1,062	1169
												2,321	2,517	7,81	17,80	56,10	5,4			1186
10				61,6	61	61	61,33	1199,5	682,3	1205,0	522,7	2,295					5,8	965,6	1,059	1023
11	5,56	5,27	63,94	61,1	61	61	61,17	1184,5	674,0	1188,0	514,0	2,304					5,6	987,9	1,062	1049
12				61,8	61	61	61,3	1199,5	683,0	1202,0	519,0	2,311					5,3	911,2	1,059	965
												2,303	2,500	7,86	18,79	58,14	5,8			1012
13																				
14																				
15																				
16																				
17																				
18																				
19																				
20																				
21																				

Specific Gravity of the Bitumen(G	1,029	%Coarse Aggr.(K%)	49,1	Bulk Spc. Gr. of the Course Aggr(Gk)	2,706
Penetration of the Bitumen=	60/70	%Fine Aggr.(I%)	43,1	Bulk Spc. Gr. of the C the Fine Aggr (Gi)	2,664
Bitumen Absorption of Aggr.(Pb	0,408	%Filler(F%)	7,8	Bulk Spc. Gr. of the Filler (Gf)	2,732
Effective Spc.Gr. of the Agg.Mix.(	2,716	Bulk Spc.Gr. Of the Agg.Mix(Gsb)=	2,687	Aggr. Content in the Briquette(gr.)	1150

The following data is obtained from Figure 3.2.2.

- •Asphalt content at maximum stability=5.00%
- •Asphalt content at maximum density=5.08%
- •Asphalt content corresponding to the maximum voids value=4.1%
- •Asphalt content providing maximum value of voids filled with asphalt=5.60%

Optimum asphalt content=(5+5.08+4.1+5.6)/4=5.0%

From the figure related to the stability vs. bitumen , stability value corresponding to 5.00% asphalt content is 1164 kg.

As it is seen from the Marshall Stability Test results , 1107 kg. stability value is obtained from the test with 30% of the reclaimed asphalt pavement. This value meets the design criteria related to the wearing course construction. With the decrease of the amount of the extracted asphalt to 20% in the mixture , the value of the stability will increase to 1164 kg. This type of mixture can also be used as base course. Thus , an important benefit of hot mix recycling method can be seen from the results that the method increases the capacity of the asphalt pavement.

It is seen from the Marshall test figures that the mixture is not incomplete conformity with the specifications in spite of its adequate stability , because the % voids is higher than 4%. Some adjustments are necessary:

- •The asphalt content can be increased,
- •More mineral filler can be added,
- •The whole gradation of the mixture can be modified.

Because of the lack of time , the adjustments that are proposed above could not be done.

CHAPTER FOUR
COST ANALYSIS

4.1 Principles of Cost Analysis

The cost analysis calculations are carried out in three steps.

1-Calculation of benefits.

2-Calculation of costs.

3- Determination of final costs.

Instead of removing a certain layer of the pavament and placing a new layer(conventional method) , if the existing material is hot recycled , the following benefits will be obtained:

- The preparation of the aggregate between 1 inch and ¾ inch.
- The preparation of the aggregate between 5/8 inch and ½ inch.
- The preparation of the aggregate between 3/8 inch and ¼ inch.
- The preparation of the bitumen.
- Transportation costs from the place the material has been extracted and to the place where it is deposited.

In the case of recycling the reusing of the aged pavement the following will be the costs:

- Over heating of the new aggregate
- Decrease in the plant capacity and other management expenses.
- Extra cost of loading.

•The transportation costs from the place the aged asphalt has been extracted and to the plant where the material will have some treatment to be reused as an asphalt pavement.

The unit costs related to the benefits and costs of hot mix recycling method are taken from The Unit Price List of the Directorate of the General Directorate of State Highways.

The following are the units costs of the year 1997:

-The preparation of the aggregate between 1 inch and ¾ inch=739,993TL/ton

-The preparation of the aggregate between 5/8 inch and ½ inch=770,676TL/ton

-The preparation of the aggregate between 3/8 inch and ¼ inch=786,019TL/ton

-The preparation of the bitumen=32,211,813TL/ton

-The extra heating cost of the aggregate=24,000TL/ton

-The decrease in the plant capacity and the increase of the management expenses=55,000TL/ton

-The extra cost of loading=6,000TL/ton

In the calculation of the expenses , the following formulas are used.

a)The cost of the transportation:

F_1=1,25*K*(0,0007*L+0,01)*A.

In this formula:

K=The coefficient which is determined by General Directorate of State Highways every year. The value of this coefficient is 8,280,000 in 1997.

A=1(Chosen according to the type and the grade of the road ; and ranges between 0-2 , generally chosen as 1)

L=The distance of transportation(km.)

b)The preparation of the aggregates:

$F_2=f_2*739,993$ where $f_2=0.19$

F_2=The cost of the aggregate between 1 inch and ¾ inch

$F_3=f_3*770,676$ where $f_3=0.237$

F_3=The cost of the aggregate between 5/8 inch and 1/2 inch

$F_4=f_4*786,019$ where $f_4=0,521$

F_4=The cost of the aggregate between

c)The preparation of the bitumen:

$F_5=f_5*32,211,813$ where $f_5=0,0021$

F_5=The cost of the bitumen

4.2 Cost Analysis Program (COSAN)

By using the above information , a computer program is prepared for evaluating the facilities of recycling for different situations. Calculations can be made for the following cases:

1-If the extraction zone and the job-site are located in the same place;

•In the case of one plant for recycling method and one plant for conventional method are present,

•In the case of two or more plants for recycling method and one plant for conventional method are present,

•If the plant for conventional method is on the job-site.

2-If the extraction zone and the job-site are located in different places;

•In the case of one plant for recycling method and one plant for conventional method are present,

•In the case of two or more plants for recycling method and one plant for conventional method are present,

•If the plant for conventional method is on the lob-site,

4.2.1 The Main Menu of the Program COSAN

When the program is started , a main menu consisting of four different options will be displayed on the screen. The options are:

1-Unit price list data.

2-Calculation of transport costs.

3-Print/Edit Output File

4-Quit to Dos

Each option is explained in the following paragraphs:

4.2.1.1. Unit Price List Data

This option is used for the input of required unit costs. A data file should be prepared for the computer program.(ex. 1997BRF.DAT). A sample data file is given in Appendix Section of the study.

4.2.1.2. Calculation of Transport Costs

This option is the main part of the program. By choosing this option , the program starts the calculation of costs analysis and the determination of final benefits.

The steps of the program are as follows:

-Input the distance between extraction zone and the deposit zone

-Calculation of costs of transportation to deposit zone

-Input number of plants that can be used for recycling

For each plant:

-Input the distance between plant and extraction zone

-Input the distance between plant and the place for laying the mixture

-Calculation of transportation costs if recycling method is preferred.

-Input the distance between plant and the place for laying the mixture if conventional method is preferred

-Calculation of transportation costs if conventional method is preferred

-Printing the unit costs and benefits for hot mix recycling method

For each plant

-Benefits if recycling method is preferred

-Costs if recycling method is preferred

-Final profit (per ton)

The flow chart of the program is given in Figure 4.1.1

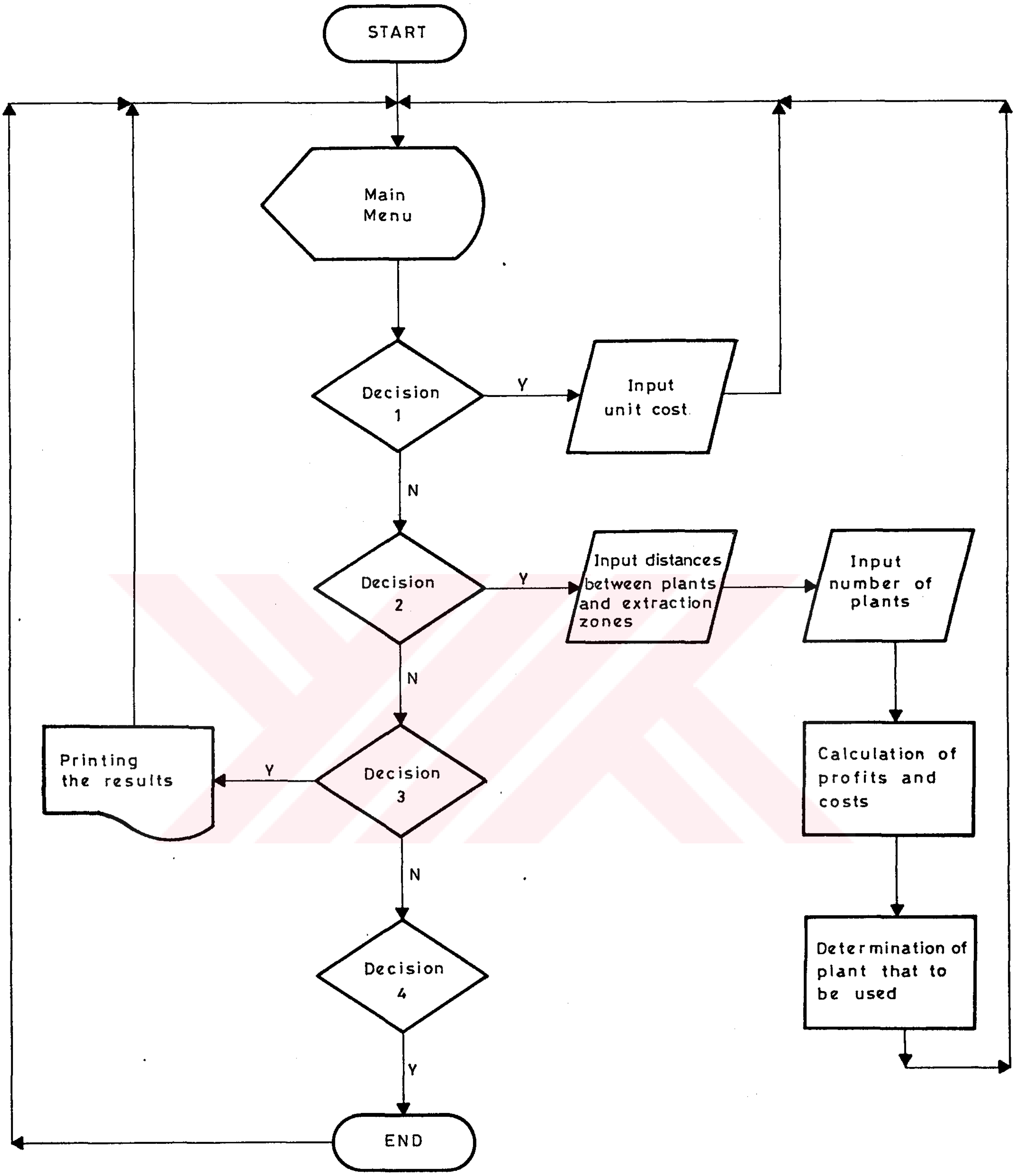


Figure 4.1.1. Flow chart.

4.2.1.3 Print/Edit Output File

This option is used for printing the results of the computer program.

4.2.1.4 Exit to Dos

This option is used for quitting the program

4.3 Benefit/Cost Analysis for the Case Study of the Ankara Street

In the calculation of costs the following example is considered. Assuming there are two plants and the extraction zone is on the Ankara Street , about 1+500 km. from the Hospital of the Ege University.

Plant 1:II. Regional Directorate of the General Directorate of State of Highways. The distance to the extraction zone is 10+000 km.

Plant:2:Izfalt.The distance to the extraction zone is 7+000 km.

Deposit Place: Levent Marina. The distance to the extraction zone is 20+000 km.

In plant I only the conventional method is performed and in plant II only the hot mix recycling method is performed.According to the given values above ; the benefits and costs calculated are as folllows:

•Cost of the transportation to the deposit zone:

F_1=1,25*K*(0,0007*L+0,01)*A

F_1=1,25*8,280,000*(0,0007*20+0,01)*1

F_1=248,400 TL/ton

•Cost of the transportation if recycling is not performed (Transportation to the II.Regional Directorate of General Directorate of the State of Highways)

F_1'=1,25*K*(0,0007*L+0,01)*A

F_1'=1,25*8,280,000*(0,007*10+0,01)*1

F_1'=175,950 TL/ton

•Cost of the transportation if recycling is performed. (Transportation to the Isfalt)

F_1''=1,25*K*(0,0007*L+0,01)*A

F_1''=1,25*8,280,000*7+0,01)*1

F_1''=308,450 TL/ton

•Preparation of the aggregates and bitumen:

F_2=f_2*739,993(Between 1 inch and ¾ inch aggregate)

F_2=0,19*739,993

F_2=140,598 TL/ton

F_3=f_3*770,676(Between 5/8 inch and ½ inch aggregate)

F_3=0,237*770,676

F_3=182,650 TL/ton

F_4=f_4*786,019(Between 3/8 inch and 1/4 inch aggregate)

F_4=0,521*786,019

F_4=409516 TL/ton

F_5=f_5*32,211,813

F_5=0,0021*32,211,813

F_5=67645 TL/ton

•Other costs:

F_6=The decrease in the plant capacity and the increase of the management expenses=55,000TL/ton

F_7=The extra cost of loading=6,000TL/ton

F_8=The extra heating cost of the aggregate=24,000TL/ton

Benefits in the case of recycling:

ΣF=F_1+F_1'+F_2+F_3+F_4+F_5

ΣF=175,950+248,400+140,598+182,650+409,516+67,645

ΣF=1,224,760 TL/ton

Costs in the case of recycling:

$\Sigma C = F_1'' + F_6 + F_7 + F_8$

$\Sigma C = 308,450 + 6000 + 24,000 + 55,000$

$\Sigma C = 393,430$ TL/ton

Final benefit will be:

$P = \Sigma F - \Sigma C$

$P = 1,244,760 - 393,430$

$P = 831,330$ TL/ton

The distance of the Plant II , where the recycling method is performed , is increased to 35+000 km. The deposit place and the place of the Plant 1 are not changed. The final benefit calculated is as follows:

•Cost of the transportation to the deposit zone:

$F_1 = 1,25 * K * (0,0007 * L + 0,01) * A$

$F_1 = 1,25 * 8,280,000 * (0,0007 * 20 + 0,01) * 1$

$F_1 = 248,400$ TL/ton

•Cost of the transportation if recycling is not performed (Transportation to the II. Regional Directorate of General Directorate of the State of Highways)

$F_1' = 1,25 * K * (0,0007 * L + 0,01) * A$

$F_1' = 1,25 * 8,280,000 * (0,007 * 10 + 0,01) * 1$

$F_1' = 175,950$ TL/ton

•Cost of the transportation is recycling is performed. (Transportation to the Isfalt)

$F_1'' = 1,25 * K * (0,0007 * L + 0,01) * A$

$F_1'' = 1,25 * 8,280,000 * 7 + 0,01) * 1$

$F_1'' = 714,150$ TL/ton

•Preparation of the aggregates and bitumen:

$F_2 = f_2 * 739,993$(Between 1 inch and ¾ inch aggregate)

$F_2 = 0,19 * 739,993$

$F_2 = 140,598$ TL/ton

$F_3=f_3*770,676$(Between 5/8 inch and ½ inch aggregate)

$F_3=0,237*770,676$

$F_3=182,650$ TL/ton

$F_4=f_4*786,019$(Between 3/8 inch and 1/4 inch aggregate)

$F_4=0,521*786,019$

$F_4=409516$ TL/ton

$F_5=f_5*32,211,813$

$F_5=0,0021*32,211,813$

$F_5=67645$ TL/ton

•Other costs:

F_6=The decrease in the plant capacity and the increase of the management expenses=55,000TL/ton

F_7=The extra cost of loading=6,000TL/ton

F_8=The extra heating cost of the aggregate=24,000TL/ton

Benefits in the case of recycling:

$\Sigma F=F_1+F_1'+F_2+F_3+F_4+F_5$

$\Sigma F=175,950+248,400+140,598+182,650+409,516+67,645$

$\Sigma F=1,224,760$ TL/ton

Costs in the case of recycling:

$\Sigma C=F_1''+F_6+F_7+F_8$

$\Sigma C=714,150+6000+24,000+55,000$

$\Sigma C=799,150$ TL/ton

Final benefit will be:

$P=\Sigma F-\Sigma C$

$P=1,244,760-799,150$

$P=425,607$ TL/ton

This means if the old pavement of the Ankara Street is hot recycled in plant , there will be a saving of 425,607 TL/ton of the asphaltic mixture to be used.

It can be clearly seen from the results of the recycling method that as the distance of the Plant II to the extraction zone increases , the cost of transportation increases where as the final benefit decreases. After several trials of increasing the distance to the plant for recycling method it is found out that the method becomes unfeasible by reaching to a distance 6 times greater than the distance to the plant for conventional method. , but as the distance to the plant increases , the loss of the heat in the extracted asphalt will become a serious problem that can not be neglected.

This computer program is not limited by the usage of only one plant that is used for performing hot mix recycling but also more than one plant have been planned for the user of this program to decide on the most profitable plant.

However it should be emphasized that cost-effectiveness is not the only factor to decide if recycling on a given road is to be used or not because there are other intangible factors such as environmental effects , conservation of natural sources etc. which should be taken into consideration and which are also in favor of recycling.

CHAPTER FIVE

CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDIES

A golden rule of our times is: The use of economic and ecological benign construction methods. Recycling process which is a time and money saving rehabilitation method suits best to this rule.

Turkey depends heavily on importation of crude oil because only a small portion (about 10%) of the total consumption is produced locally. In addition the increase of tandem axle loads to 19 tones and single axle load to 13 tones in July 1985 brings the necessity of more rehabilitation as well as the maintenance on the existing highway network. Thus an important result of this investigation is that the recycling procedures offer considerable potential economic benefit to Turkey which use extensively bituminous materials.

As there is no production of asphalt emulsion for roads in Izmir cold recycling tests could not be performed in laboratory. The tests include only the hot mix recycling processes. This process improves the structural capacity of the road. As it is seen from the Marshall Test results , 1107 kg. stability value is achieved in the test with 30% of the reclaimed asphalt pavement. This value increased the stability to 1164 kg. when 20% of the reclaimed asphalt pavement is used.

It is seen that the recycled mixture can be used either in wearing or in base courses as far as the stability is concerned. Recycled wearing course can also be overlaid by a slurry seal or microasphalt concrete if necessary.

From the computer program , the following can be obtained:
In the case of two plants ; one of them is located in Izfalt asphalt production center on the Ankara Street and can be used for performing the hot mix recycling method , the other is located in the II. Regional Directorate of General Directorate of the State of Highways and can be used for performing conventional methods ;

- The total benefit in the preference of recycling (leaving the conventional method) is 1,224,760 TL/ton
- The total cost in the case of recycling process is 393,430 TL/ton

The final profit will be 831,329 TL/ton. Thus another important result can be derived from this investigation that the recycling procedure reduces demand for new bitumen and saves energy.

In spite of the advantages of recycling procedure , the following disadvantages cannot be neglected:

- Potential air pollution problems
- Potential mix design problems
- The difficulty in the control of satisfactory quality

There is no consensus with regard to the long term success of recycling. It should be noted that no evidence is found in the catastrophic failure after about five years experience with the process.

In Turkey the recycling process is not widespread at present and no serious attempt has been paid in spite of the material , energy and cost savings offered. Only recently General Directorate of the State of Highways has started to work on a project on the Birecik-Harbur road in which the hot recycling method will be used.

As further study , it would be interesting to investigate in detail also cold recycling method which may be more feasible especially in urban areas.

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APPENDIX A

THE COMPUTER PROGRAM

```
DECLARE SUB alarm ()
DECLARE SUB ARKA ()
DECLARE SUB kontrol (satir, bx, by, cx, cy, a1$, a2$, a3$, a4$, a5$, bn$, C$(),
kon, secilen)
DECLARE SUB Cerceve (Satir1%, Sutun1%, Satir2%, Sutun2%, Tip$)
DECLARE SUB PoPupMenu (Sat%, Sut%, Secenekler$(), SonucKodu%)

1 CLS

 SCREEN 0
DIM SecenekDizisi$(4)

CLS

CALL ARKA

REDIM C$(4)
satir = 4
bx = 12: by = 23
cx = 13: cy = 20
a3$ = "    COST ANALYSIS OF RECYCLED PAVEMENTS      "
bn$ = "MAIN MENU"
menua$(1) = " 1. Unit price List Data                    "
menua$(2) = " 2. Calculation of Transport Costs          "
menua$(3) = " 3. Print/Edit Output File                  "
menua$(4) = " 4. Quit to DOS                             "
'yukle
FOR k = 1 TO satir
   C$(k) = menua$(k)
```

```
NEXT
kon = 1
CALL kontrol(satir, bx, by, cx, cy, a1$, a2$, a3$, a4$, a5$, bn$, C$(), kon, secilen)

IF secilen = 1 THEN GOTO 2
IF secilen = 2 THEN GOTO 10000
IF secilen = 3 THEN GOTO 30000
IF secilen = 4 THEN GOTO 200000

2 CLS

CALL ARKA

DIM X(100), Z(100), Y(100)

satir% = 11
Sutun% = 10

COLOR 7, 4: Cerceve satir% - 2, Sutun% - 1, 12, 75, "..."

FOR J = 10 TO 11
LOCATE J, 10: COLOR 7, 4: PRINT "                                                   "
NEXT J

3 LOCATE 10, 10: COLOR 7, 4: PRINT "Please choose the file you want to open:"
LOCATE 11, 10: INPUT "(if not known please type [FILES] and press enter)"; D$
IF D$ = "files" OR D$ = "FILES" THEN GOTO 4 ELSE GOTO 5
4 FOR J = 14 TO 20
LOCATE J, 1: COLOR 7, 2: PRINT "
"; ""
NEXT J
```

```
LOCATE 15, 25: FILES "*.DAT": GOTO 3
5 OPEN D$ FOR INPUT AS #1

CLS

INPUT #1, b$, k, b1$, a, b2$, Brf1, b3$, Brf2, b4$, Brf3, b5$, BtBrf
INPUT #1, b6$, Yukilvcal, b7$, dgrislmal, b8$, agistmal

CALL ARKA


LOCATE 5, 7: COLOR 4, 10: PRINT "   Unit Price Cost Values   "
LOCATE 6, 8: COLOR 8, 8: PRINT "                          "
LOCATE 8, 3: COLOR 7, 2: PRINT "  Description   "
LOCATE 9, 4: COLOR 8, 8: PRINT "              "
LOCATE 8, 63: COLOR 7, 2: PRINT "Values (in TL)"
LOCATE 9, 64: COLOR 8, 8: PRINT "             "

FOR I = 10 TO 21
LOCATE I, 3: COLOR 7, 6: PRINT "                                                    "
NEXT I

FOR I = 10 TO 21
LOCATE I, 60: COLOR 7, 1: PRINT "               "
NEXT I

FOR I = 11 TO 22
LOCATE I, 77: COLOR 8, 8: PRINT " "
NEXT I

FOR I = 4 TO 77
```

```
LOCATE 22, I: COLOR 8, 8: PRINT " "
NEXT I

LOCATE 11, 4: COLOR 7, 6: PRINT b$
LOCATE 11, 62: COLOR 7, 1: PRINT k
LOCATE 12, 4: COLOR 7, 6: PRINT b1$
LOCATE 12, 62: COLOR 7, 1: PRINT a
LOCATE 13, 4: COLOR 7, 6: PRINT b2$
LOCATE 13, 62: COLOR 7, 1: PRINT Brf1
LOCATE 14, 4: COLOR 7, 6: PRINT b3$
LOCATE 14, 62: COLOR 7, 1: PRINT Brf2
LOCATE 15, 4: COLOR 7, 6: PRINT b4$
LOCATE 15, 62: COLOR 7, 1: PRINT Brf3
LOCATE 16, 4: COLOR 7, 6: PRINT b5$
LOCATE 16, 62: COLOR 7, 1: PRINT BtBrf
LOCATE 17, 4: COLOR 7, 6: PRINT b6$
LOCATE 17, 62: COLOR 7, 1: PRINT Yukilvcal
LOCATE 18, 4: COLOR 7, 6: PRINT b7$
LOCATE 18, 62: COLOR 7, 1: PRINT dgrislmal
LOCATE 19, 4: COLOR 7, 6: PRINT b8$
LOCATE 19, 62: COLOR 7, 1: PRINT agistmal

SLEEP 30

GOTO 1

10000 REM tas□ma maliyetinin hesab□

CLS
```

```
CALL ARKA

satir% = 3
Sutun% = 4

COLOR 7, 4: Cerceve satir% - 2, Sutun% - 1, 11, 79, "..."

FOR J = 2 TO 10
LOCATE J, 4: COLOR 7, 4: PRINT "
"
NEXT J

LOCATE 3, 5: COLOR 7, 12: INPUT "Distance between extraction and deposite
zones="; Atkmes

F1 = 1.25 * k * (.0007 * Atkmes + .01) * a

LOCATE 4, 5: COLOR 7, 12: PRINT "Cost of transport to the deposite zone="; F1

LOCATE 5, 5: COLOR 2, 12: INPUT "Please enter the number of plents that can bu
used for recycling="; N

FOR I = 1 TO N
10010  LOCATE 6, 5: COLOR 7, 12: PRINT "Plent:"; I
LOCATE 7, 5: COLOR 7, 12: INPUT "Distance between plent and extraction
zone="; X(I)
LOCATE 8, 5: COLOR 7, 12: INPUT "Distance between plent and place for laying
the mixture="; Z(I)
```

```
F2 = 1.25 * k * (.0007 * X(I) + .01) * a
F3 = 1.25 * k * (.0007 * Z(I) + .01) * a

Y(I) = F2 + F3

LOCATE 9, 5: COLOR 7, 12: PRINT "Transport cost if recycling is done(in TL)=";
Y(I)
LOCATE 10, 5: COLOR 10, 12: PRINT "(Please push any botton for the next plent
or to continue)"

SLEEP

İF N > 1 AND N < I THEN GOTO 10010

NEXT I


satir% = 14
Sutun% = 4

COLOR 7, 1: Cerceve satir% - 2, Sutun% - 1, 15, 79, "..."

FOR J = 13 TO 14
LOCATE J, 4: COLOR 7, 1: PRINT "
"
NEXT J


LOCATE 13, 5: COLOR 7, 1: INPUT "Distance between plent and the laying area if
recycling is not done="; pltsanmes
```

```
F4 = 1.25 * k * (.0007 * pltsanmes + .01) * a

LOCATE 14, 5: COLOR 7, 1: PRINT "Transport cost to the laying area if recycling
is not done="; F4


satir% = 18
Sutun% = 4

COLOR 7, 13: Cerceve satir% - 2, Sutun% - 1, 22, 79, "..."

FOR J = 17 TO 21
LOCATE J, 4: COLOR 7, 13: PRINT "
"
NEXT J


LOCATE 17, 5: COLOR 4, 13: PRINT "Preference of recycling"

F5 = .19 * Brf1
F6 = .237 * Brf2
F7 = .521 * Brf3
F8 = .0021 * BtBrf

LOCATE 18, 5: COLOR 7, 13: PRINT "1 and 3/4 inc. agregate cost="; F5
LOCATE 19, 5: COLOR 7, 13: PRINT "5/8 and 1/2 inc. agregate cost="; F6
LOCATE 20, 5: COLOR 7, 13: PRINT "3/8 and 1/4 inc. agregate cost="; F7
LOCATE 21, 5: COLOR 7, 13: PRINT "Asphalt cement cost="; F8
```

```
SLEEP 30

CLS

CALL ARKA


satir% = 5
Sutun% = 4

COLOR 7, 4: Cerceve satir% - 2, Sutun% - 1, 11, 75, "..."

FOR J = 4 TO 10
LOCATE J, 4: COLOR 7, 4: PRINT "                                                   "
NEXT J



LOCATE 6, 5: COLOR 7, 4: PRINT "Expenses in case of recycling"

LOCATE 7, 5: COLOR 7, 4: PRINT b6$; Yukilvcal,
LOCATE 8, 5: COLOR 7, 4: PRINT b7$; dgrislmal
LOCATE 9, 5: COLOR 7, 4: PRINT b8$; agistmal

SLEEP

F9 = Yukilvcal + dgrislmal + agistmal


satir% = 14
Sutun% = 4
```

```
COLOR 7, 1: Cerceve satir% - 2, Sutun% - 1, 18, 75, "..."

FOR J = 13 TO 17
LOCATE J, 4: COLOR 7, 1: PRINT "                                              "
NEXT J


FOR I = 1 TO N
10020 LOCATE 14, 5: COLOR 7, 1: PRINT "Plent"; I

fayda = F1 + F4 + F5 + F6 + F7 + F8

LOCATE 15, 5: COLOR 7, 1: PRINT "Profit cost incase of recycling="; fayda

zarar = Y(I) + F9

LOCATE 16, 5: COLOR 7, 1: PRINT "Expenses incase of recycling="; zarar

gelir = fayda - zarar

LOCATE 17, 5: COLOR 14, 1: PRINT "Final profit per tone="; gelir

IF N > 1 AND N < I THEN GOTO 10020

SLEEP

NEXT I

satir% = 21
Sutun% = 4
```

```
COLOR 7, 14: Cerceve satir% - 2, Sutun% - 1, 23, 75, "..."

FOR J = 20 TO 22
LOCATE J, 4: COLOR 7, 14: PRINT "
"
NEXT J

LOCATE 20, 5: COLOR 7, 14: INPUT "Do you want to save the results?(y/n)"; C$

IF C$ = "y" OR C$ = "Y" THEN GOTO 20000
IF C$ = "n" OR C$ = "N" THEN GOTO 1

20000 CLS

CALL ARKA

satir% = 10
Sutun% = 11

COLOR 7, 1: Cerceve satir% - 2, Sutun% - 1, 15, 70, "..."

FOR J = 9 TO 14
LOCATE J, 11: COLOR 7, 1: PRINT "                                                    "
NEXT J

LOCATE 10, 13: COLOR 7, 1: INPUT "Please enter the output file's name:"; O$

OPEN O$ FOR OUTPUT AS #2

PRINT #2, b$; k
```

```
PRINT #2, b1$; a
PRINT #2, b2$; Brf1
PRINT #2, b3$; Brf2
PRINT #2, b4$; Brf3
PRINT #2, b5$; BtBrf
PRINT #2, b6$; Yukilvcal
PRINT #2, b7$; dgrislmal
PRINT #2, b8$; agistmal

PRINT #2, "Distance between extraction and deposite zones="; Atkmes
PRINT #2, "Cost of transport to the deposite zone="; F1
PRINT #2, "The number of plents that can bu used for recycling="; N

FOR I = 1 TO N

PRINT #2, "Plent:"; I
PRINT #2, "Distance between plent and extraction zone="; X(I)
PRINT #2, "Distance between plent and place for laying the mixture="; Z(I)
PRINT #2, "Transport cost if recycling is done(in TL)="; Y(I)

NEXT I

PRINT #2, "Distance between plent and the laying area if recycling is not done=";
pltsanmes
PRINT #2, "Transport cost to the laying area if recycling is not done="; F4
PRINT #2, "Preference of recycling"
PRINT #2, "1 and 3/4 inc. agregate cost="; F5
PRINT #2, "5/8 and 1/2 inc. agregate cost="; F6
PRINT #2, "3/8 and 1/4 inc. agregate cost="; F7
PRINT #2, "Asphalt cement cost="; F8
```

```
PRINT #2, "Expenses in case of recycling"
PRINT #2, b6$; Yukilvcal,
PRINT #2, b7$; dgrislmal
PRINT #2, b8$; agistmal

FOR I = 1 TO N

PRINT #2, "Plent"; I
PRINT #2, "Profit cost incase of recycling="; fayda
PRINT #2, "Expenses incase of recycling="; zarar
PRINT #2, "Final profit per tone="; gelir

NEXT I

LOCATE 11, 13: COLOR 7, 1: PRINT "File saved succesfully"

SLEEP

GOTO 1

30000 CLS

CALL ARKA


satir% = 11
Sutun% = 10

COLOR 7, 4: Cerceve satir% - 2, Sutun% - 1, 12, 75, "..."

FOR J = 10 TO 11
```

```
LOCATE J, 10: COLOR 7, 4: PRINT "                                              "
NEXT J

30003 LOCATE 10, 10: COLOR 7, 4: PRINT "Please choose the file you want to
open:"
LOCATE 11, 10: INPUT "(if not known please type [FILES] and press enter)"; P$
IF P$ = "files" OR P$ = "FILES" THEN GOTO 30004 ELSE GOTO 30005
30004 FOR J = 14 TO 20
LOCATE J, 1: COLOR 7, 2: PRINT "
"; ""
NEXT J
LOCATE 15, 25: FILES "*.OUT": GOTO 30003

30005 SHELL "edit" + P$
fd:



200000 CLS
END

SUB alarm
BEEP
END SUB

SUB ARKA

COLOR 0, 3
FOR I = 1 TO 23
FOR J = 1 TO 79
LOCATE I, J: PRINT "°²"
```

```
NEXT J
NEXT I

END SUB

SUB Cerceve (Satir1%, Sutun1%, Satir2%, Sutun2%, Tip$)

IF Tip$ = "É" THEN
  Solust$ = "É"
  Solalt$ = "È"
  Sagust$ = "»"
  Sagalt$ = "¼"
  Yatay$ = "Í"
  Dikey$ = "º"
ELSE
  Solust$ = "Ú"
  Solalt$ = "À"
  Sagust$ = "¿"
  Sagalt$ = "Ù"
  Yatay$ = "Ä"
  Dikey$ = "³"

END IF

LOCATE Satir1%, Sutun1%: PRINT Solust$
LOCATE Satir2%, Sutun1%: PRINT Solalt$
LOCATE Satir1%, Sutun2%: PRINT Sagust$
LOCATE Satir2%, Sutun2%: PRINT Sagalt$

FOR I = Sutun1% + 1 TO Sutun2% - 1
LOCATE Satir1%, I: PRINT Yatay$
```

```
LOCATE Satir2%, I: PRINT Yatay$
NEXT I

FOR I = Satir1% + 1 TO Satir2% - 1
LOCATE I, Sutun1%: PRINT Dikey$
LOCATE I, Sutun2%: PRINT Dikey$
NEXT I


END SUB

 SUB kontrol (satir, bx, by, cx, cy, a1$, a2$, a3$, a4$, a5$, bn$, C$(), kon, secilen)

'koord□nat (bx,by) (cx,cy)
DEF SEG = &HB800
cx = cx - 1

2020  COLOR 7, 8: 'normal ekran renkleri
COLOR 15, 1
         LOCATE 2, 3, 0: PRINT a1$
         LOCATE 3, 3, 0: PRINT a2$;
COLOR 15, 4: LOCATE 8, 20, 0: PRINT a3$;
         LOCATE 9, 20, 0: PRINT a4$;
COLOR 0, 0:  LOCATE 10, 21, 0: PRINT a5$
         LOCATE 9, 66, 0: PRINT " "
'shadow
'LOCATE cx + 1 + satir, 21, 0: PRINT SPC(46);
  COLOR 7, 8, 0
  'baŸl□k
  LOCATE bx, by: COLOR 2, 6: PRINT SPC(1); bn$; SPC(1);
2100  COLOR 0, 7
```

```
  FOR J = 1 TO satir
  uzunluk = LEN(C$(J))
  LOCATE cx + J, cy, 0: PRINT C$(J)
  IF J > 1 THEN COLOR 0, 0: LOCATE cx + J, cy + uzunluk: PRINT " "
  IF J = satir THEN LOCATE cx + satir + 1, cy + 1: PRINT SPC(uzunluk);
  COLOR 0, 7
  NEXT
s = 0: I = 0
  LOCATE 2, 68: PRINT "          "
  LOCATE 3, 68: PRINT "          ";

2300 a$ = INKEY$
   IF a$ = "" THEN
   LOCATE 2, 69: PRINT ; TIME$;
    LOCATE 3, 69: PRINT DATE$;
   GOTO 2300
  END IF
  IF a$ = CHR$(13) THEN GOTO 4300
  IF LEN(a$) <> 2 THEN CALL alarm: GOTO 2100
  a$ = MID$(a$, 2, 1)
  IF a$ = "M" THEN : CALL alarm: GOTO 2100 'tuŸ iptal sag
  IF a$ = "K" THEN : CALL alarm: GOTO 2100 'tuŸ iptal sol
  IF a$ = "P" THEN I = I + 1 'yukar□ ok
  IF a$ = "H" THEN I = I - 1 'aŸag□ ok
' IF A$ = "P" OR A$ = "M" THEN i = i + 1    'tuŸ kontrol
' IF A$ = "H" OR A$ = "K" THEN i = i - 1   'tuŸ kontrol azaltma
  IF I > satir THEN I = 1
  IF I < 1 THEN I = satir
3100 GOSUB 3800
   FOR k = 1 TO satir
```

```
  IF I = k THEN COLOR 3, 12: LOCATE cx + k, cy, 0: PRINT C$(k): s = I:
GOTO 3600
  NEXT
3600 COLOR 0, 7, 0
3700 GOTO 2300
3800 IF s = 0 THEN RETURN
  FOR k = 1 TO satir
   IF s = k THEN : LOCATE cx + k, cy, 0: PRINT C$(k): s = I: RETURN
  NEXT
  FOR k = 0 TO satir
   IF s = k THEN : LOCATE cx + k, cy, 0: PRINT C$(k - 1): s = I: RETURN
  NEXT
4300 IF s = 0 THEN 2300
  'se‡im kontrol
 FOR J = 1 TO satir
   IF s = satir AND kon = 1 THEN CLS : SYSTEM
   IF s = J THEN : secilen = s: kon = 0: GOTO 4610
 NEXT
4610 ERASE C$




END SUB

SUB PoPupMenu (Sat%, Sut%, Secenekler$(), SonucKodu%)

ElemanSayisi = UBOUND(Secenekler$)

FOR I = 1 TO ElemanSayisi
LOCATE Sat% + I - 1, Sut%: PRINT Secenekler$(I)
```

```
NEXT I

Sira = 1

POPupMenutekrar:
LOCATE Sat% + Sira - 1, Sut%: COLOR 0, 7
PRINT Secenekler$(Sira): COLOR 7, 0



DO
Tus$ = INKEY$
LOOP WHILE Tus$ = " "


LOCATE Sat% + Sira - 1, Sut%: COLOR 7, 12
PRINT Secenekler$(Sira)

SELECT CASE Tus$
    CASE CHR$(27)
        SonucKodu% = 0
        EXIT SUB

    CASE CHR$(13)
        SonucKodu% = Sira
        EXIT SUB

    CASE CHR$(0) + CHR$(72)
        Sira = Sira - 1

    CASE CHR$(0) + CHR$(80)
        Sira = Sira + 1
```

```
END SELECT

      IF Sira < 1 THEN Sira = ElemanSayisi

      IF Sira > ElemanSayisi THEN Sira = 1

      GOTO POPupMenutekrar

END SUB
```

APPENDIX B

FIGURES AND TABLES RELATED TO RECYCLING PROCESS

Figure 2.1.1 Roadway with Severe Cracking

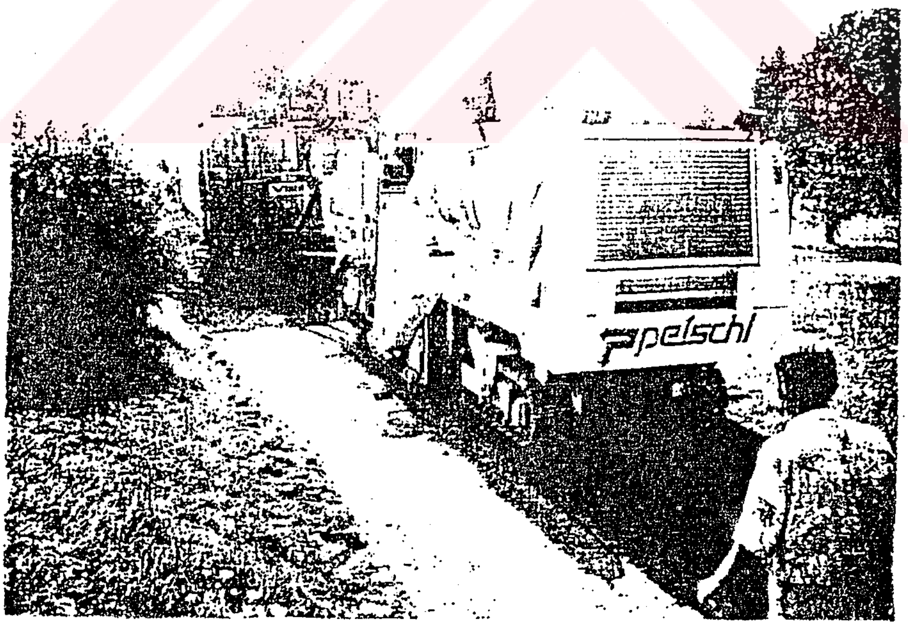

Figure 2.1.2 In Place Recycling

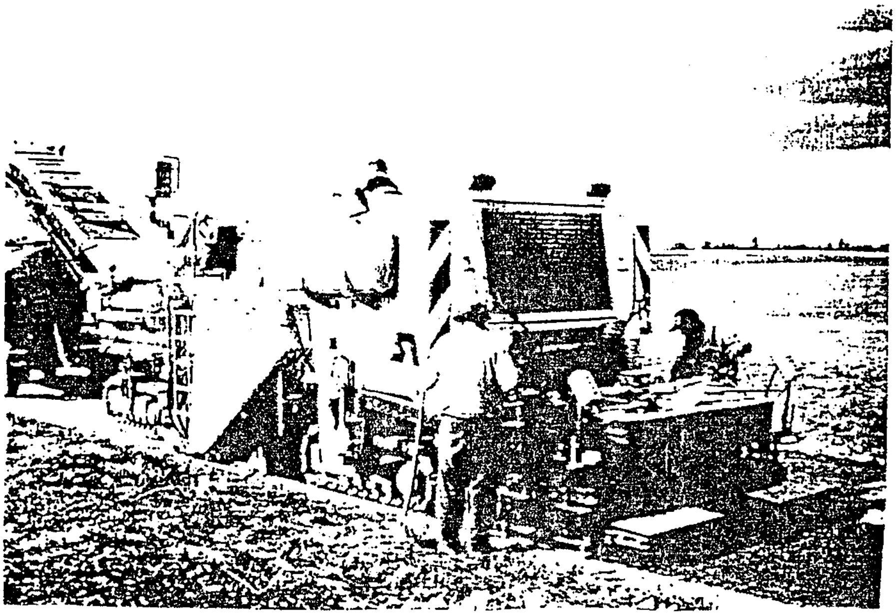

Figure 2.1.3 Rehabilitation with the Wirtgen 2100 DC-R

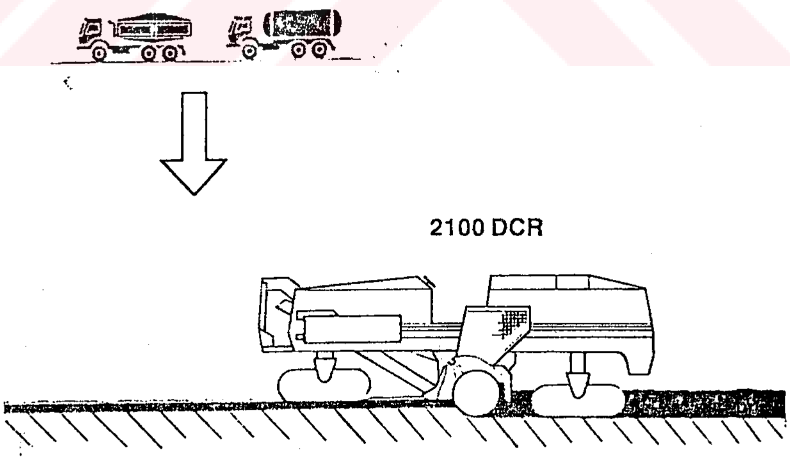

Figure 2.1.4 Restoration work with Cement and Emulsion

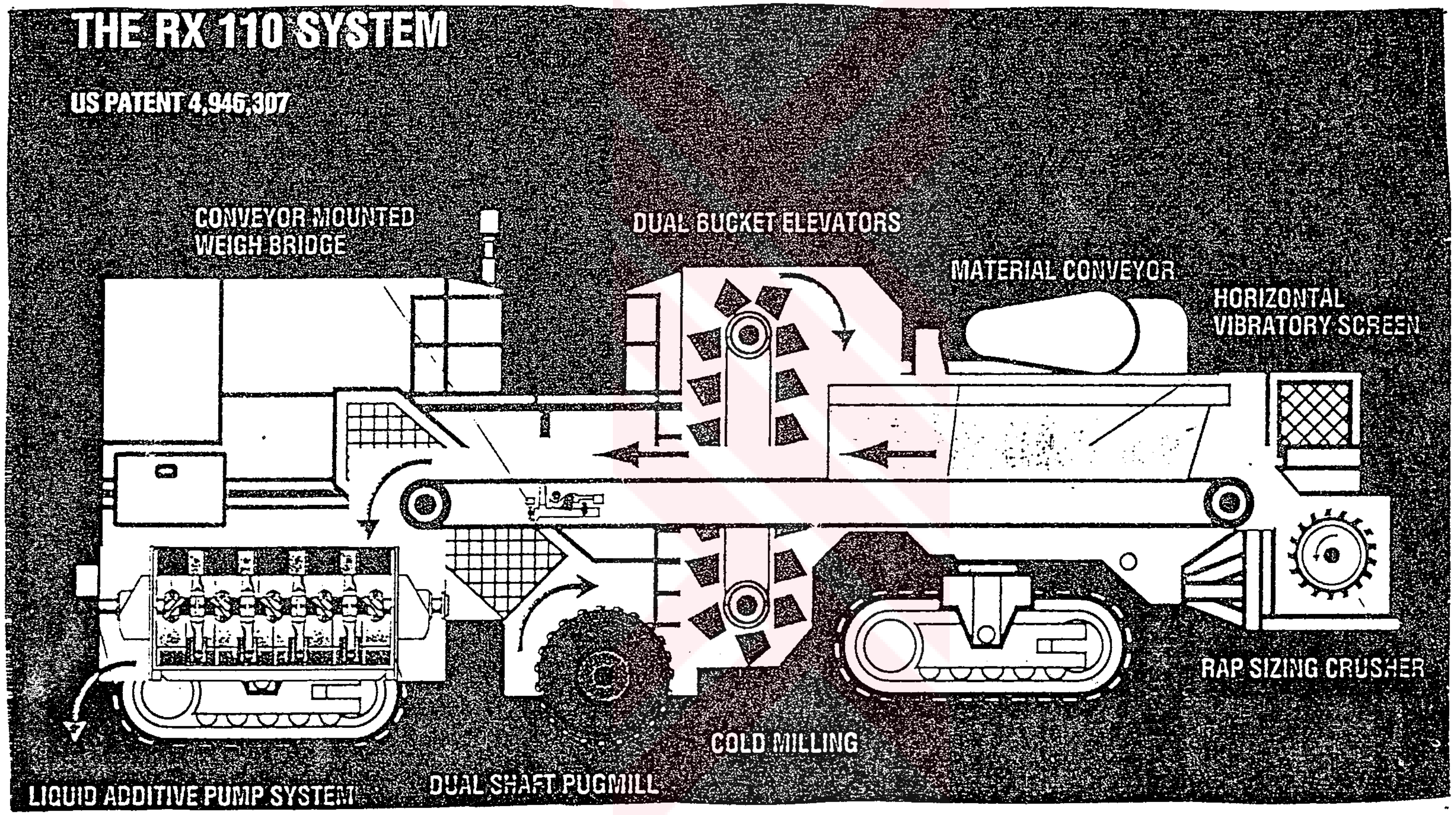

Figure 2.1.5 The RX 110 System Cold Recycling Machine

Figure 2.1.6 The 1000 CR Cold Recycling Machine

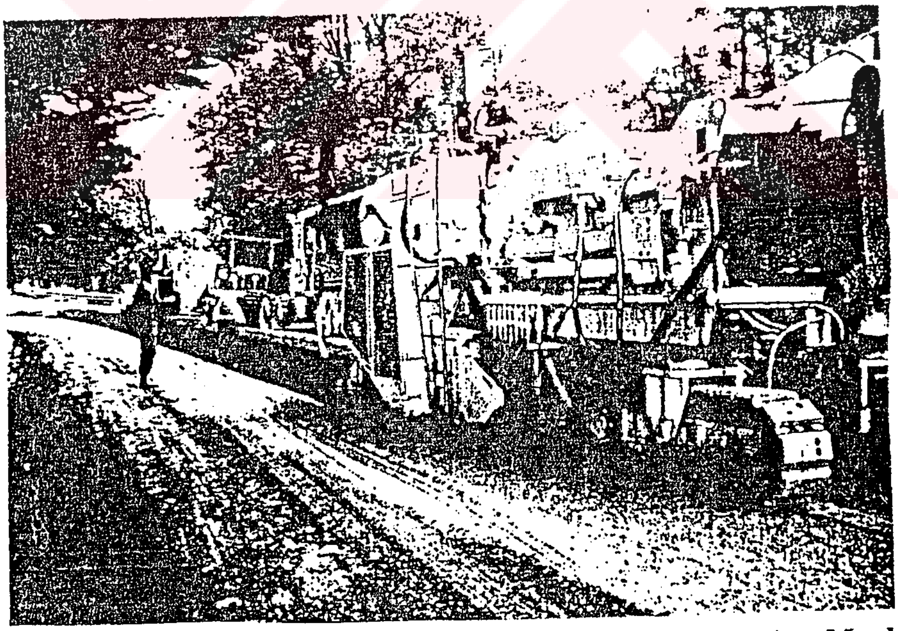

Figure 2.1.7 The 2100 DC-R Cold Recycler with a Milling Machine

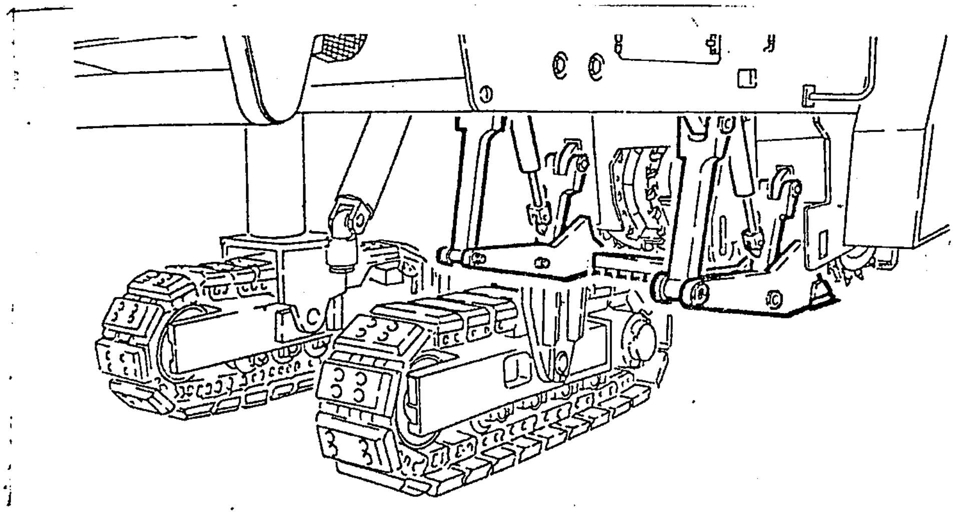

Figure 2.1.8 The Gradation Control Beam of 2100 DC-R

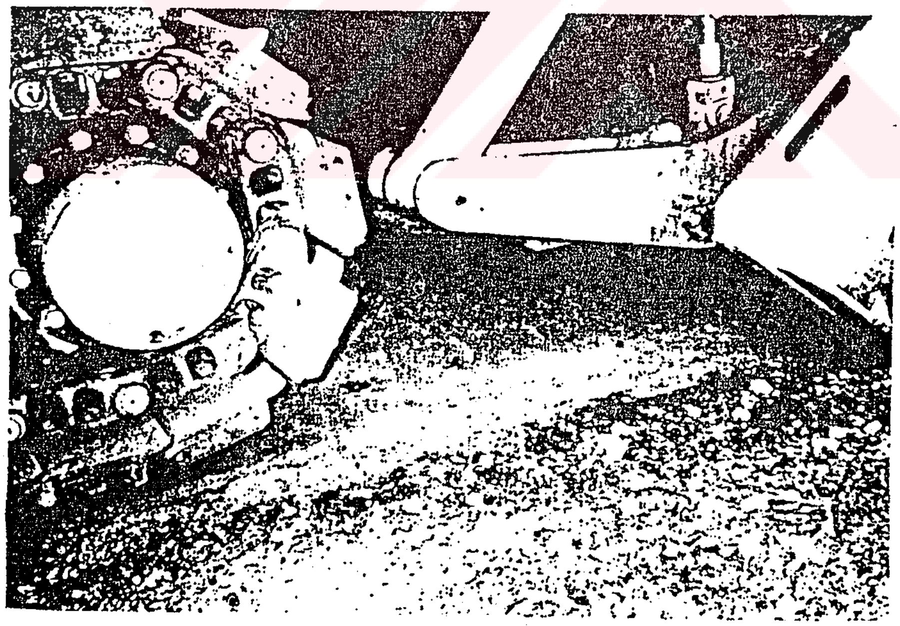

Figure 2.1.9 The Gradation control Beam of 2100 DC-R

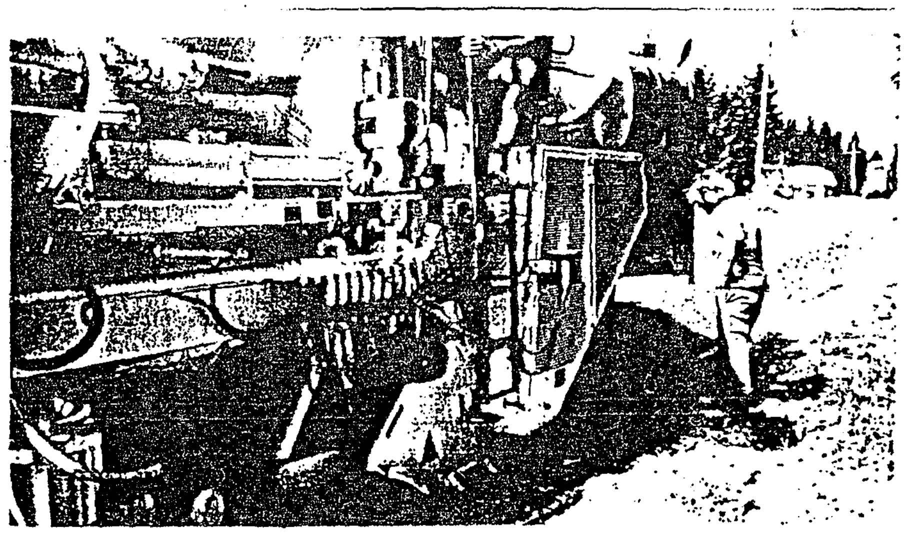

Figure 2.1.10 Binder Spray System of 2100 DC-R

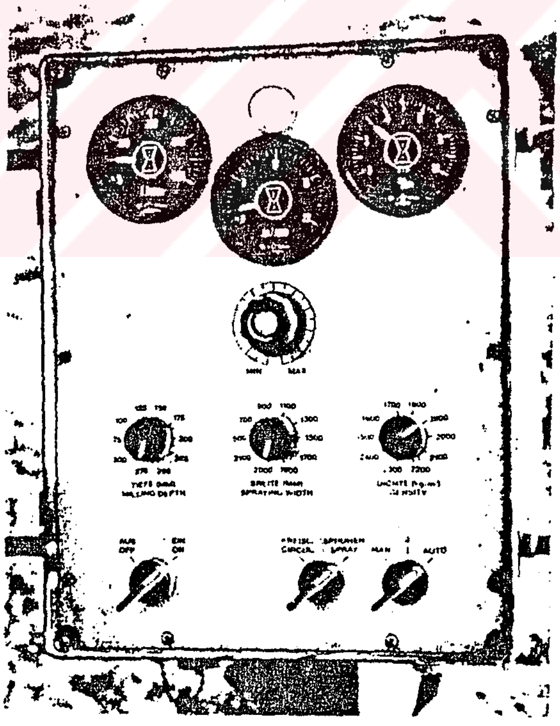

Figure 2.1.11 Microprocessor Controlled Spraying System

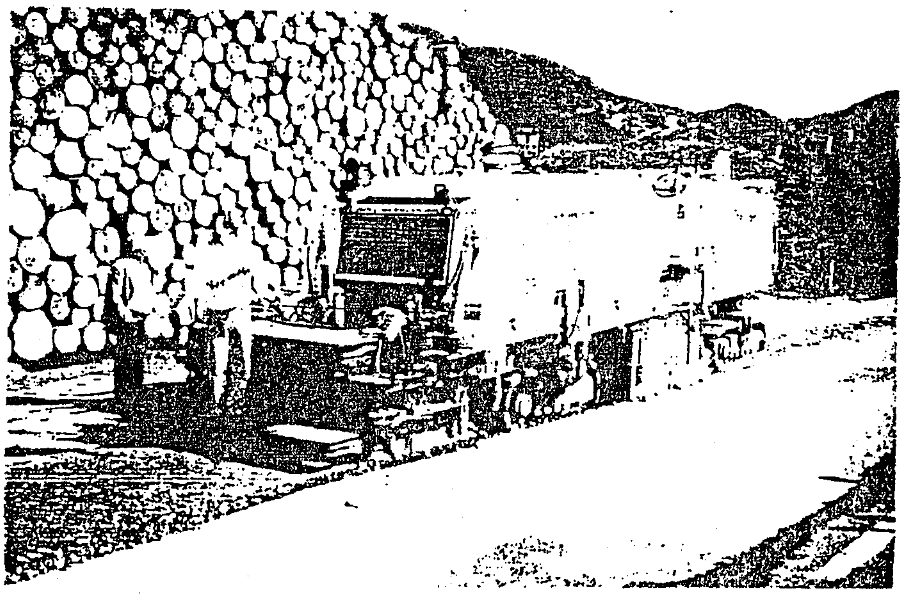

Figure 2.1.12 The Screed with 2100 DC-R

Figure 2.1.13 Self Propelled Cement Spreader

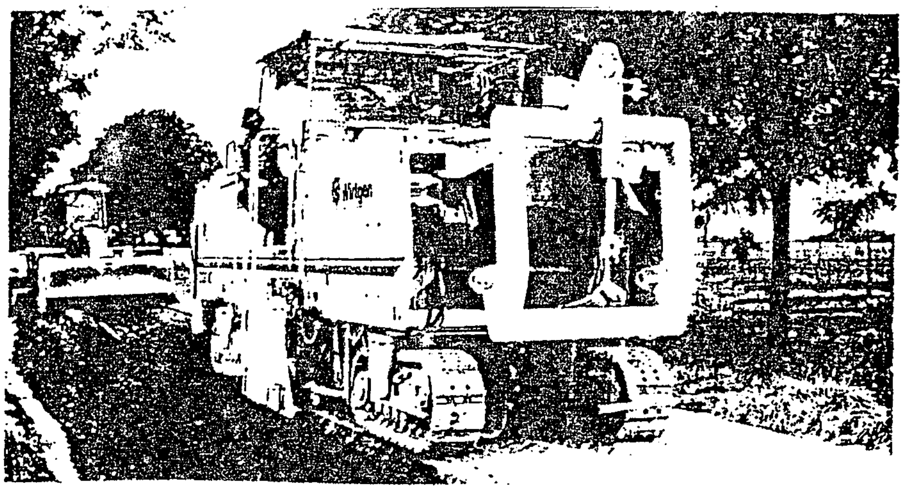

Figure 2.1.14 Laying Material with Grader

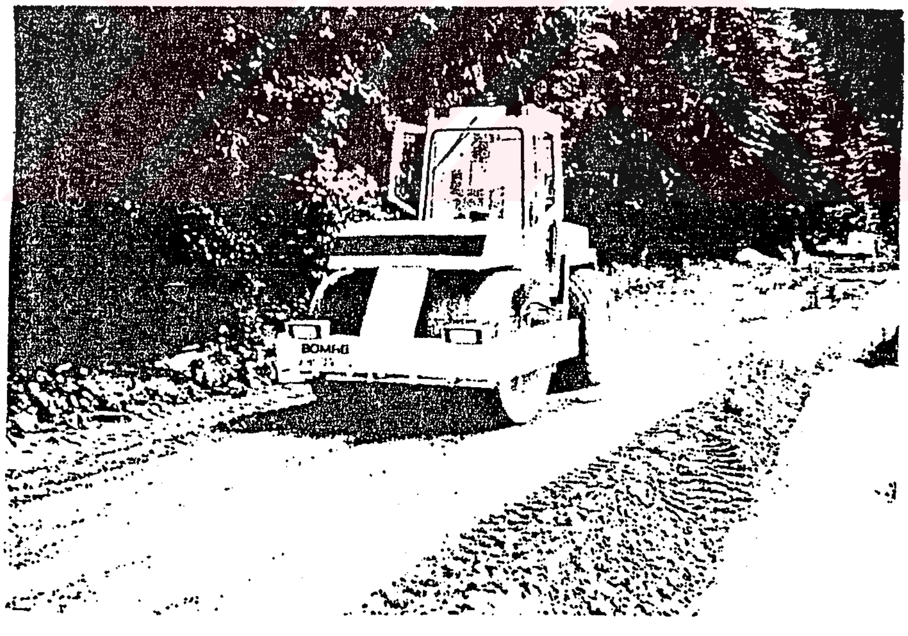

Figure 2.1.15 Compaction of the Recycled Layer

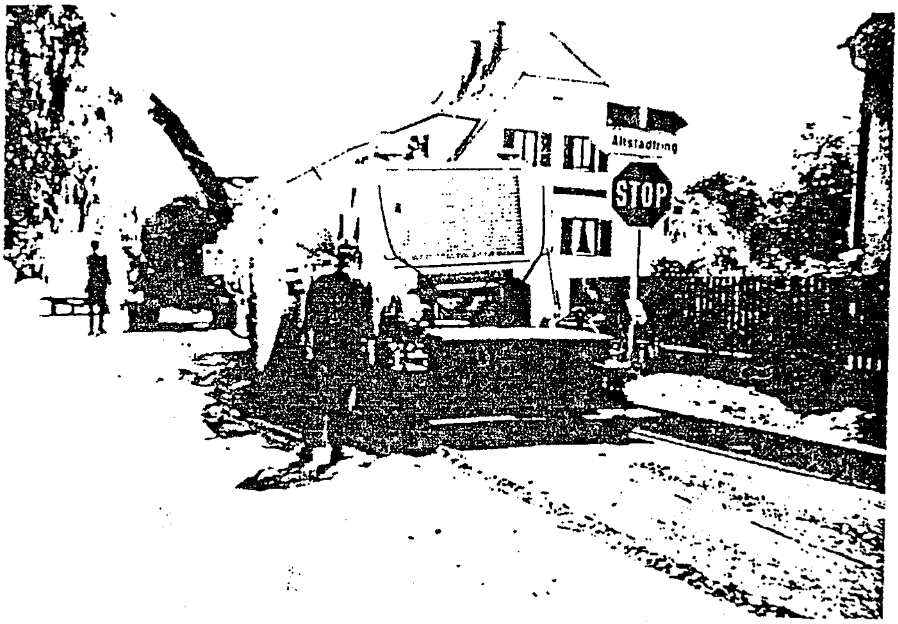

Figure 2.1.16 Cold Recycling with Bitumen Emulsion

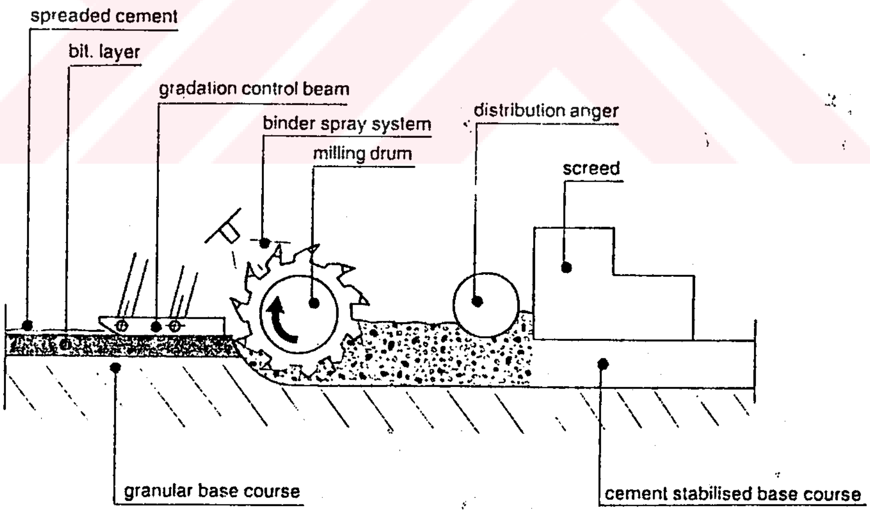

Figure 2.1.17 Cold recycling with Cement and Bitumen Emulsion

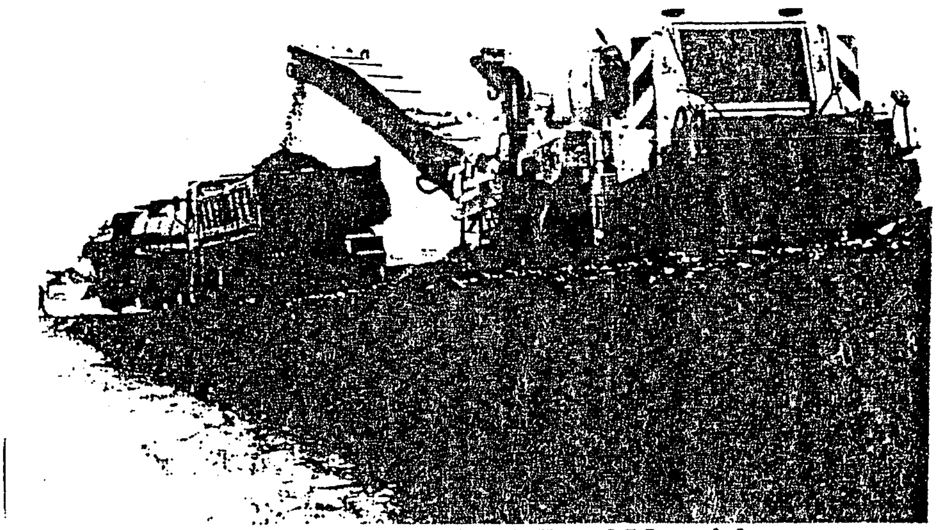

Figure 2.1.18 Cold Recycling with Polluted Materials

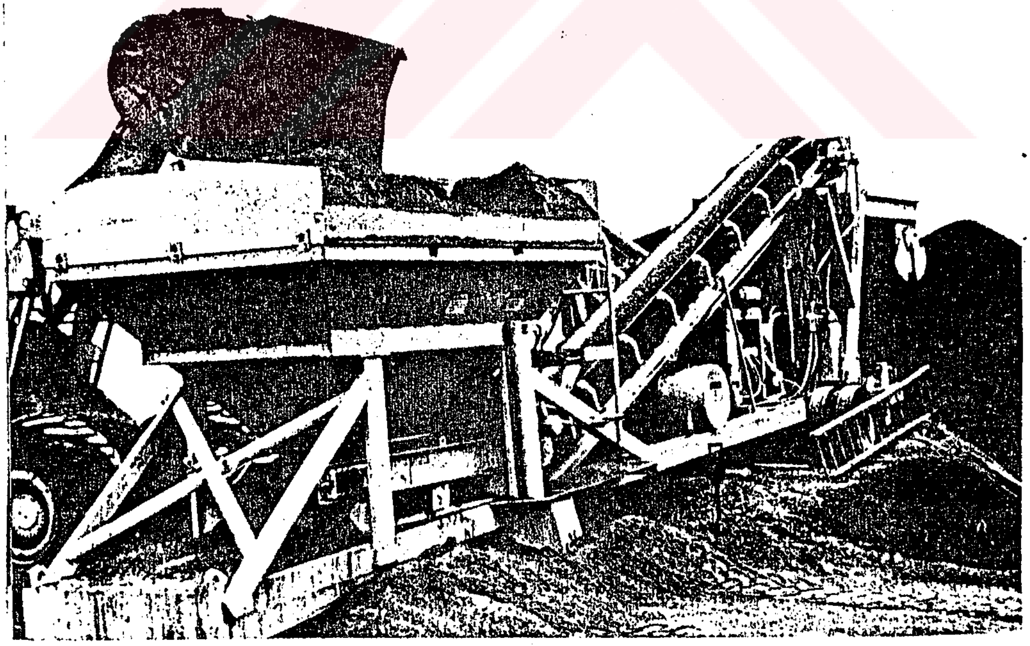

Figure 2.1.19 Continous Type Plant

Figure 2.1.20 Loading Track with Recycled Material

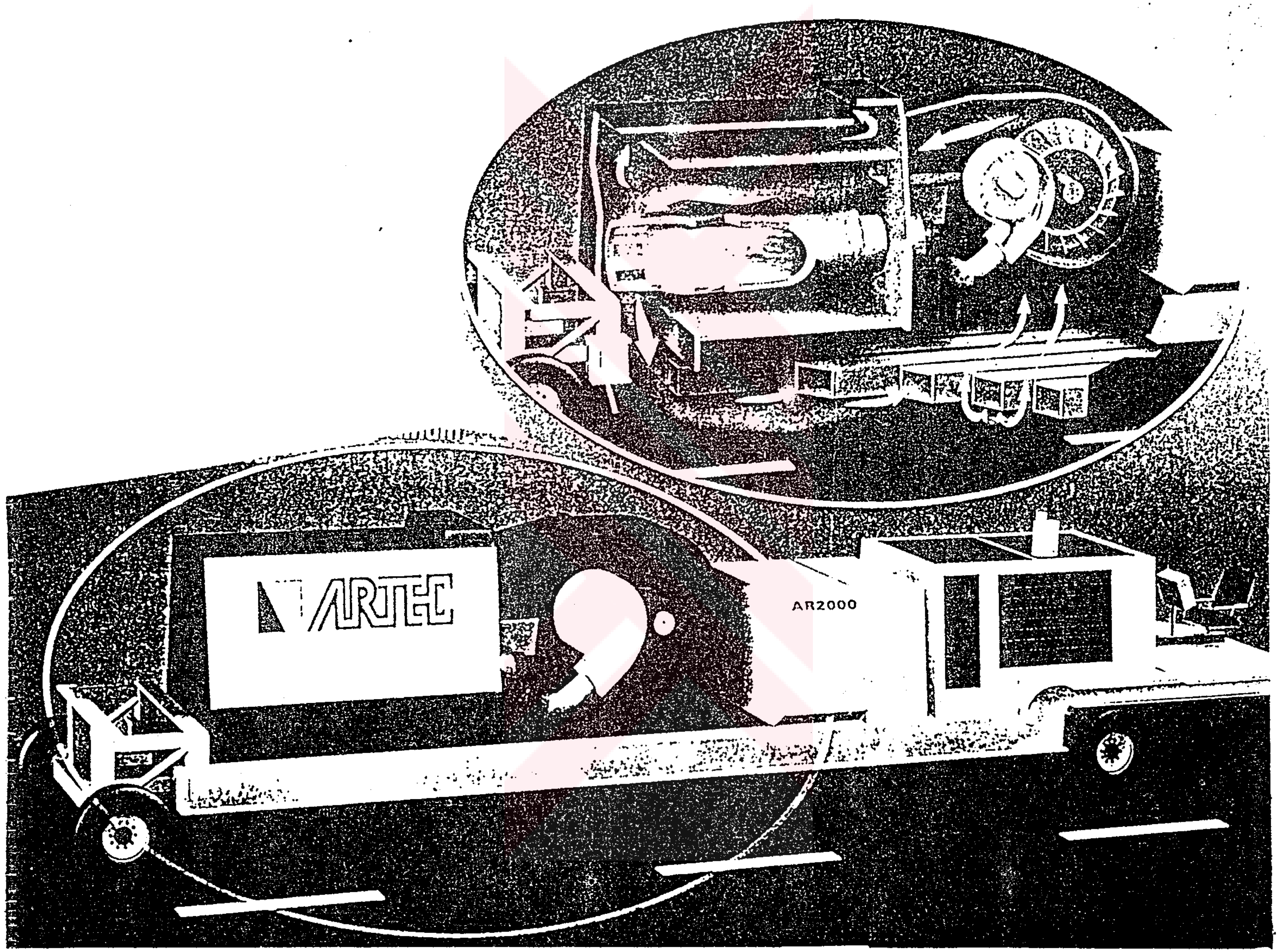

Figure 2.2.1 Combustion Camber of the AR 2000 Thermo Jet Sysytem

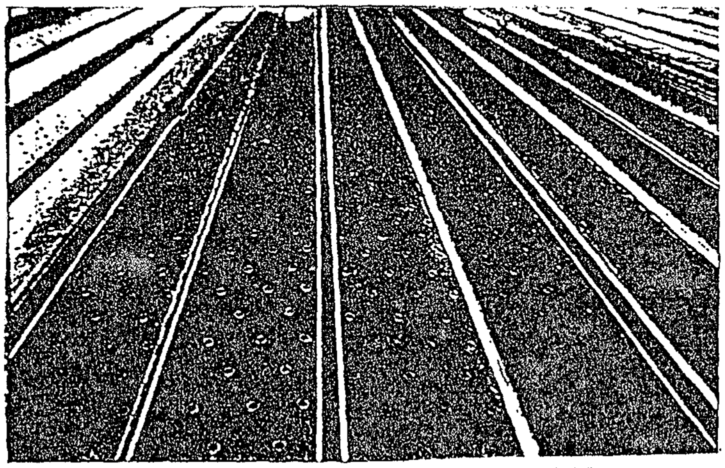

Figure 2.2.2 Small Tubes of the AR 2000

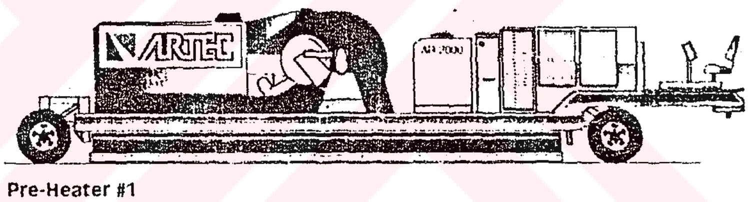

Figure 2.2.3 Pre Heater Section of the AR 2000

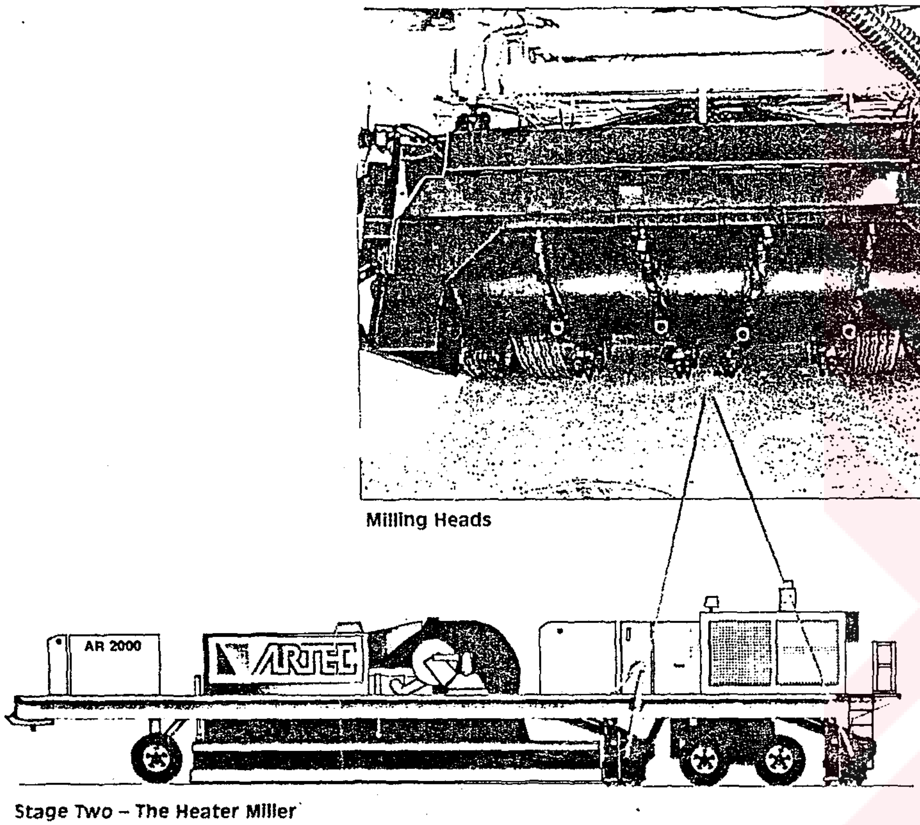

Figure 2.2.4 The Heater Miller Section of the AR 2000

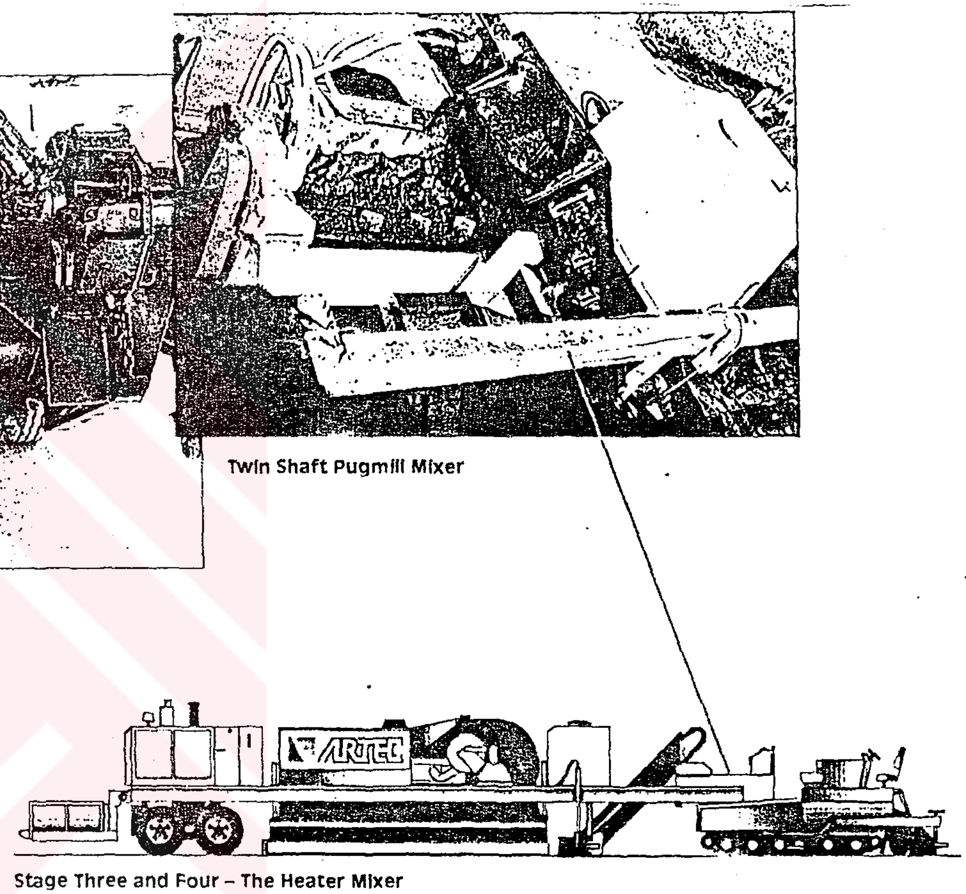

Figure 2.2.5 The Heater Mixer Section of the AR 2000

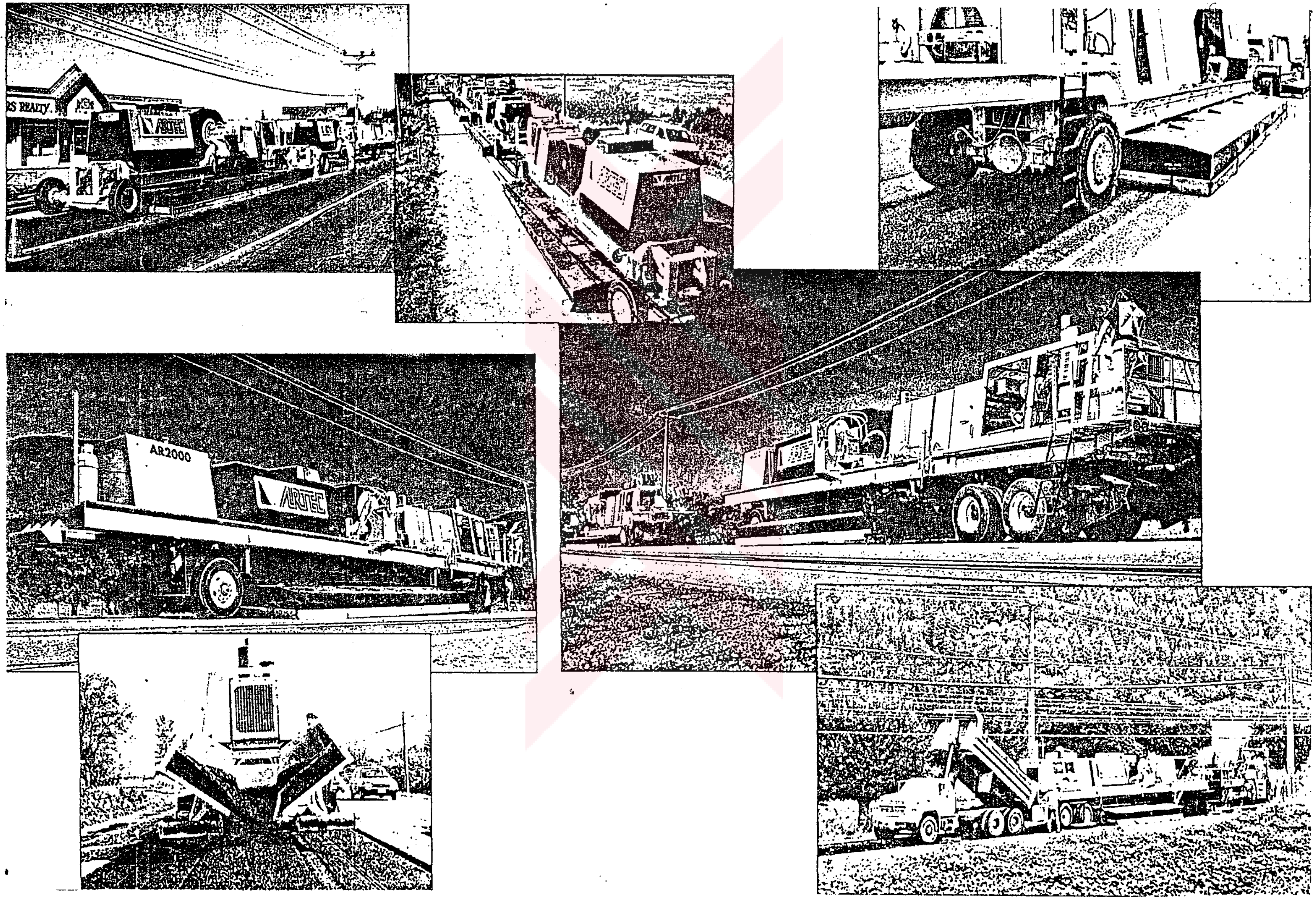

Figure 2.2.6 The General Aspects of the AR 2000

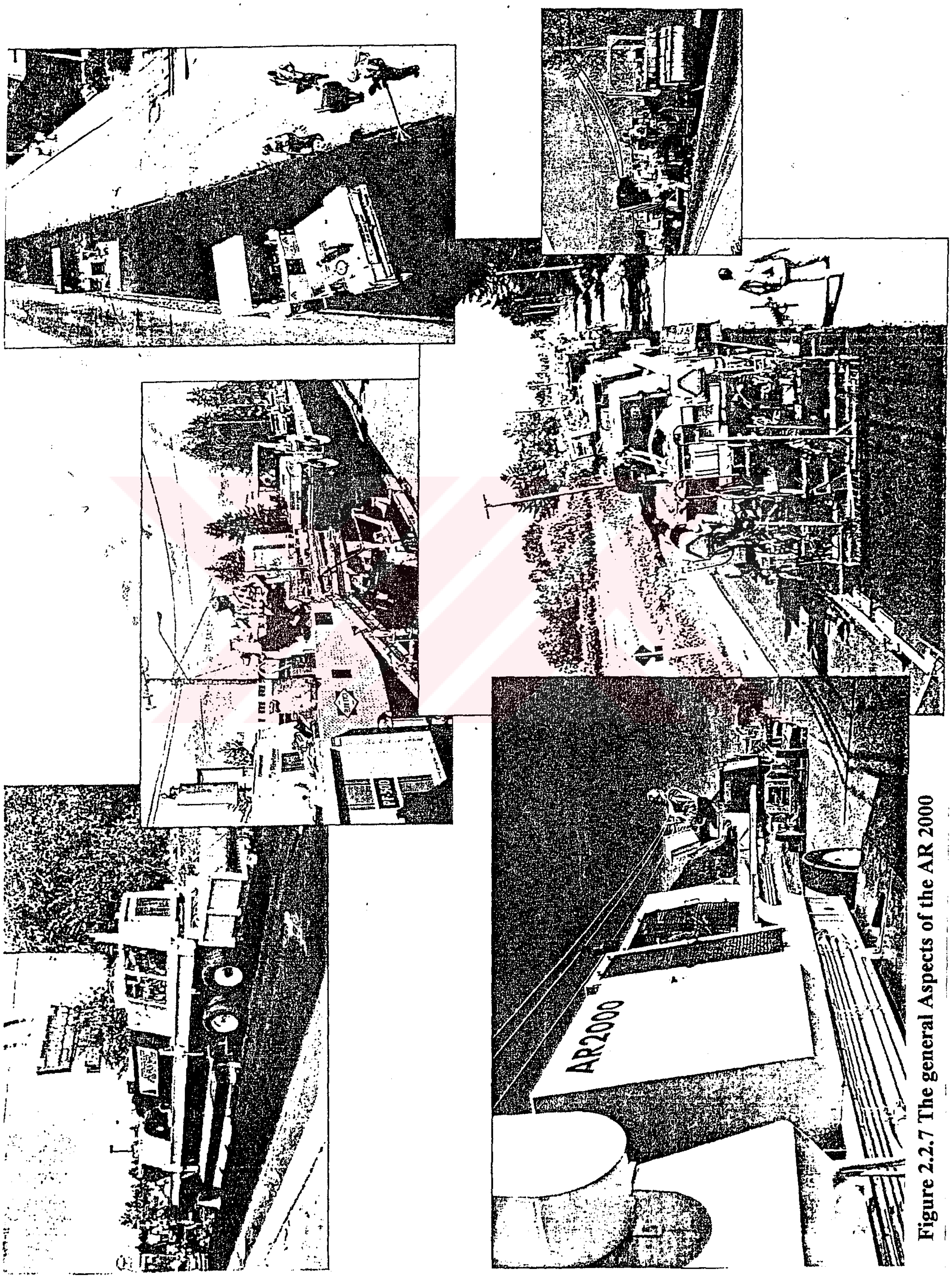

Figure 2.2.7 The general Aspects of the AR 2000

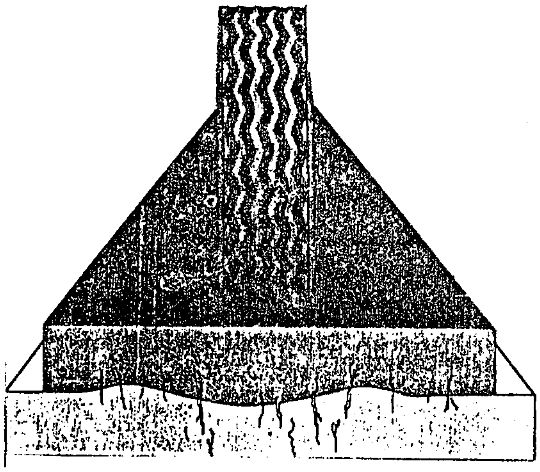

Figure 2.2.8 Defect on a Pavement

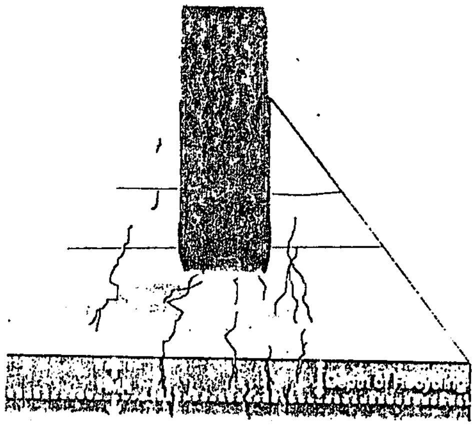

Figure 2.2.9 Cracking on a Pavement

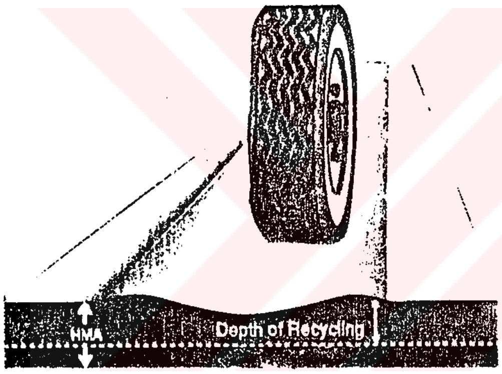

Figure 2.2.10 Rutting on a Pavement

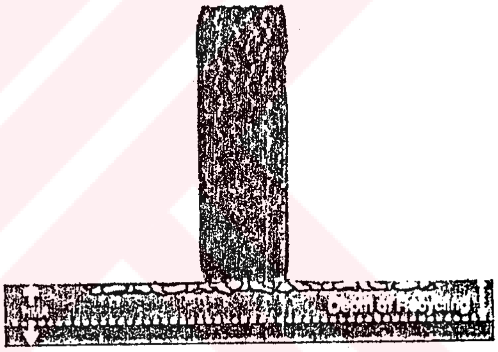

Figure 2.2.11 Ravelling on a Pavement

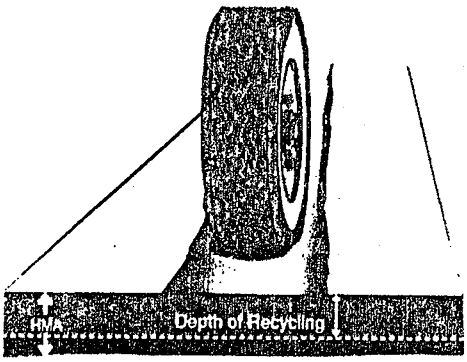

Figure 2.2.12 Bleeding on a Pavement

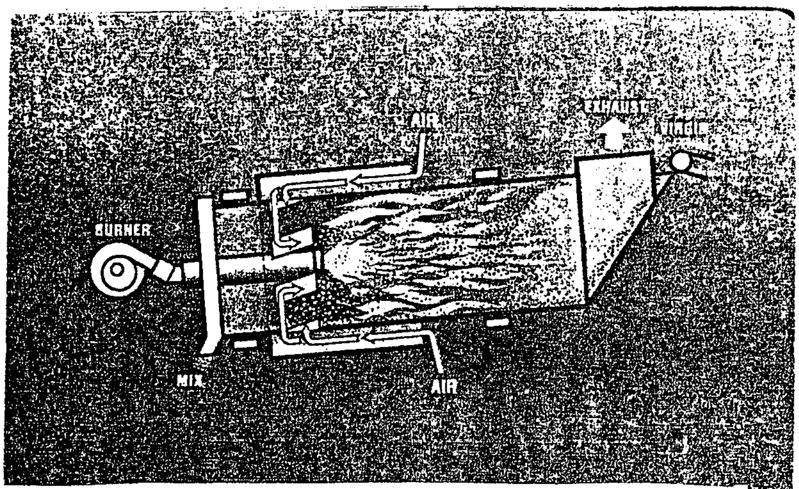

Figure 2.2.13 Counter Flow Dryer Aircooled Shell

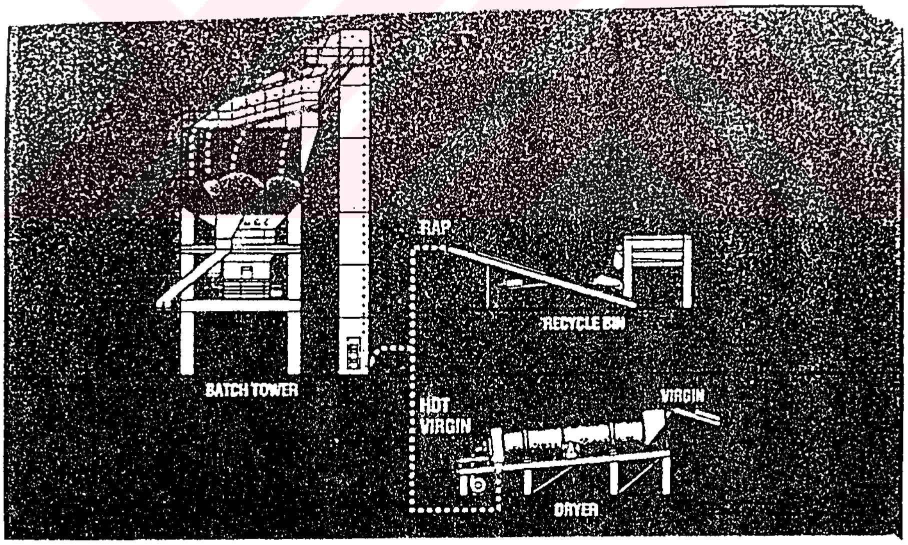

Figure 2.2.14 Batch Type Plant

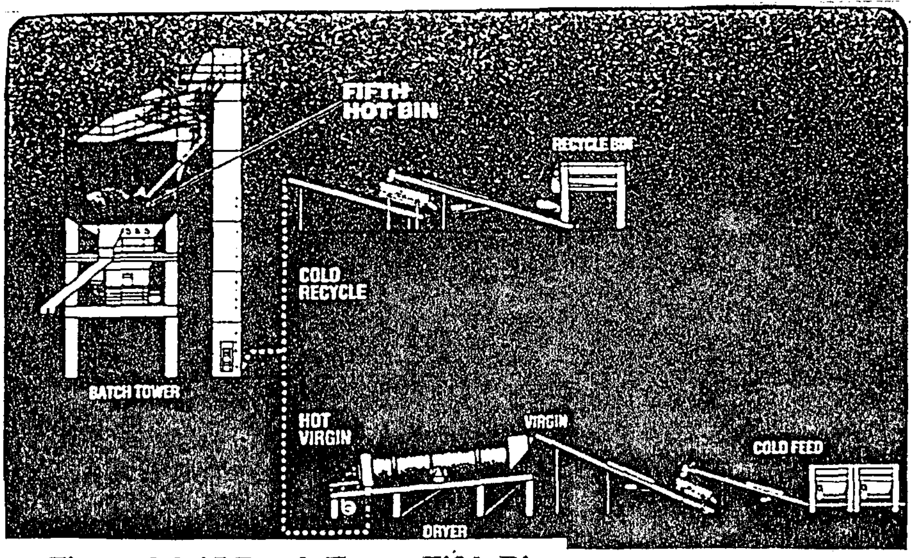

Figure 2.2.15 Batch Tower Fifth Bin

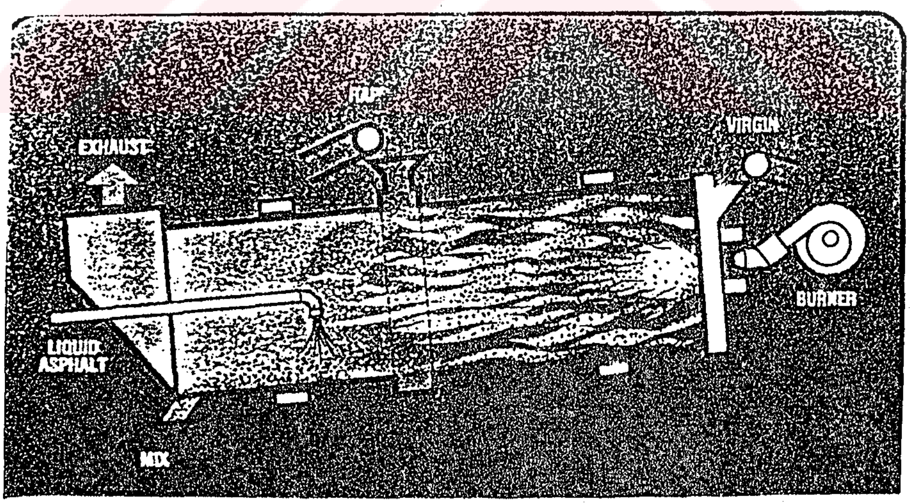

Figure 2.2.16 Parallel Flow Drum Mix Plant

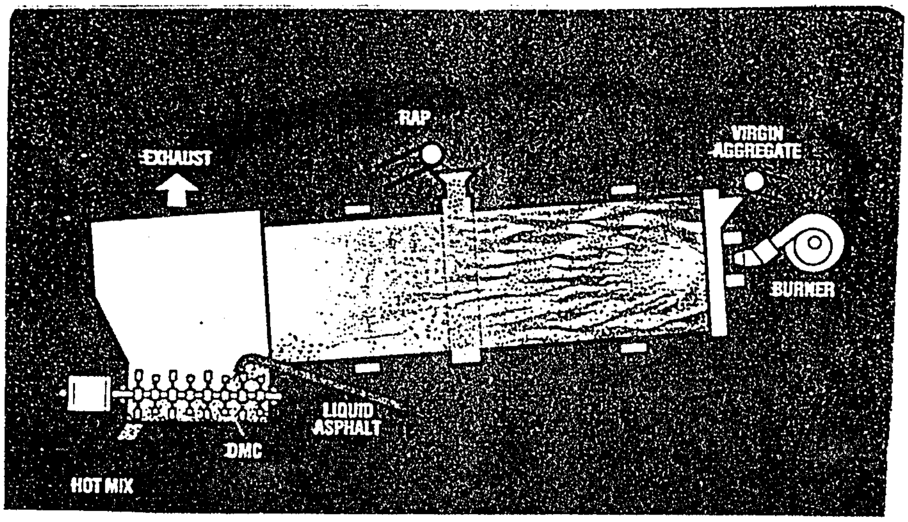

Figure 2.2.17 Drum Mixer Coater

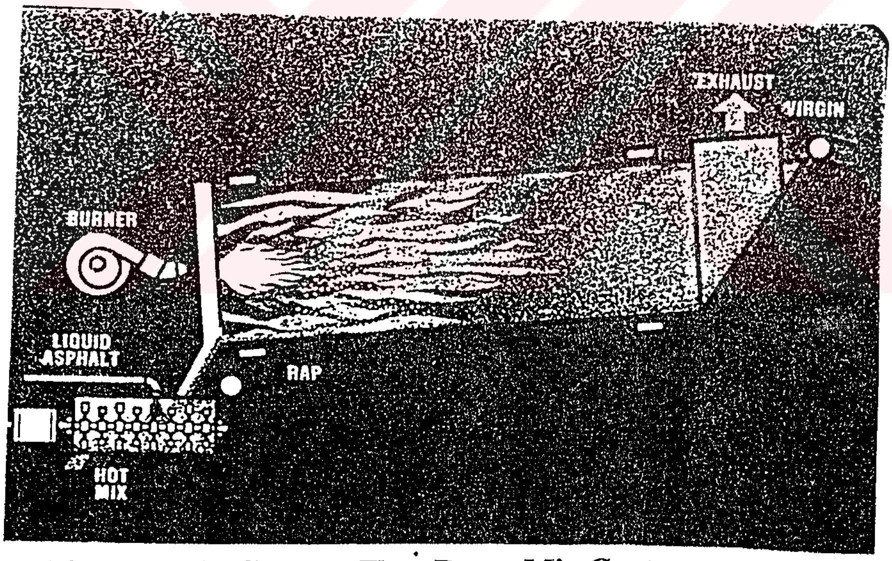

Figure 2.2.18 Counter Flow Drum Mix Coater

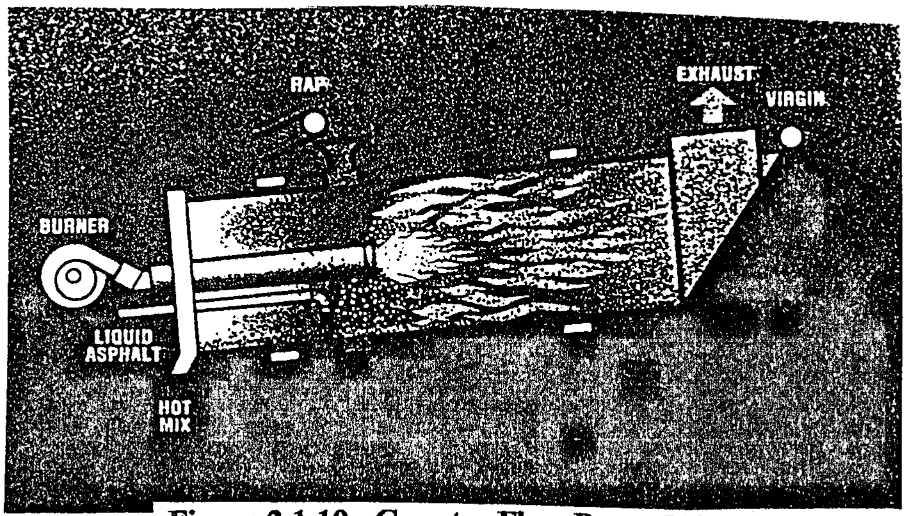

Figure 2.1.19 Counter Flow Drum Mixer

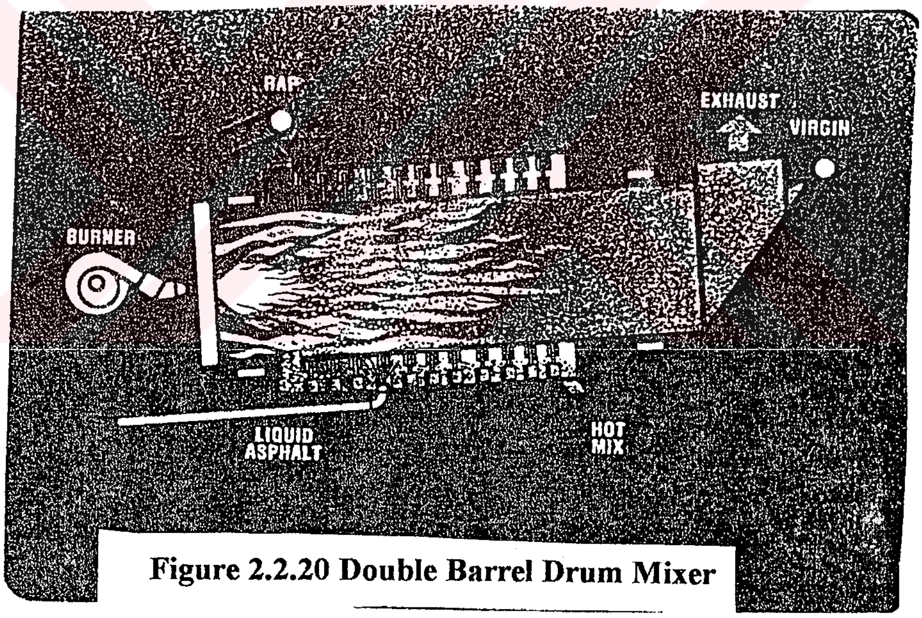

Figure 2.2.20 Double Barrel Drum Mixer

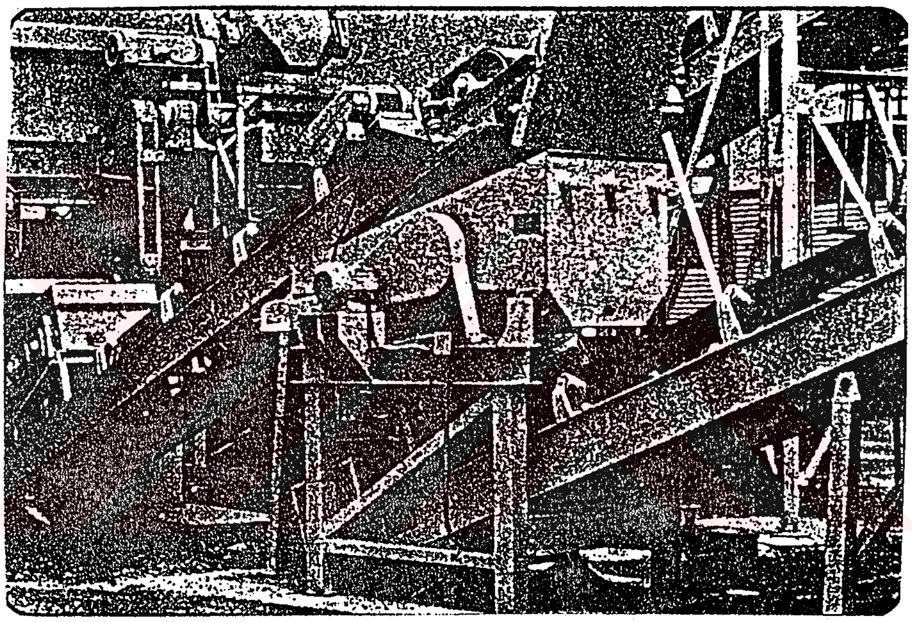

Figure 2.2.21 Screened Recycled Asphalt Pavement

Table 2.2.1 Required Aggregate Temperatures

Reclaimed Material Moisture Content, %	Recycled Mix Discharge Temperature							
	104°C	(220°F)	116°C	(240°F)	127°C	(260°F)	138°C	(280°F)
A. RATIO: 10% RAP/90% Aggregate								
0	121	(250)	138	(280)	152	(305)	163	(325)
1	127	(260)	143	(290)	154	(310)	168	(335)
2	132	(270)	146	(295)	157	(315)	171	(340)
3	138	(280)	149	(300)	163	(325)	174	(345)
4	141	(285)	152	(305)	166	(330)	177	(350)
5	143	(290)	157	(315)	168	(335)	182	(360)
B RATIO 20% RAP/80% Aggregate								
0	138	(280)	154	(310)	168	(335)	182	(360)
1	146	(295)	160	(320)	177	(350)	191	(375)
2	154	(310)	168	(335)	182	(360)	196	(385)
3	163	(325)	177	(350)	191	(375)	204	(400)
4	171	(340)	185	(365)	199	(390)	213	(415)
5	179	(355)	193	(380)	207	(405)	221	(430)
RATIO 30% RAP/70% Aggregate								
0	157	(315)	174	(345)	191	(375)	207	(405)
1	168	(335)	185	(365)	202	(395)	218	(425)
2	182	(360)	199	(390)	216	(420)	232	(450)
3	196	(385)	213	(415)	229	(445)	246	(475)
4	210	(410)	227	(440)	243	(470)	260	(500)
5	224	(435)	241	(465)	257	(495)	274	(525)
RATIO 40% RAP/60% Aggregate								
0	179	(355)	199	(390)	218	(425)	238	(460)
1	199	(390)	218	(425)	238	(460)	257	(495)
2	218	(425)	238	(460)	257	(495)	277	(530)
3	243	(470)	260	(500)	279	(535)	299	(570)
4	260	(500)	279	(535)	299	(570)	321	(610)
5	285	(545)	302	(575)	321	(610)	341	(645)
E RATIO: 50% RAP/50% Aggregate								
0	210	(410)	235	(455)	257	(495)	282	(540)
1	241	(465)	268	(515)	288	(550)	310	(590)
2	271	(520)	293	(560)	318	(605)	343	(650)
3	302	(575)	327	(620)	349	(660)	374	(705)
4	338	(640)	360	(680)	379	(715)	404	(760)
5	366	(690)	391	(735)	413	(775)	438	(820)