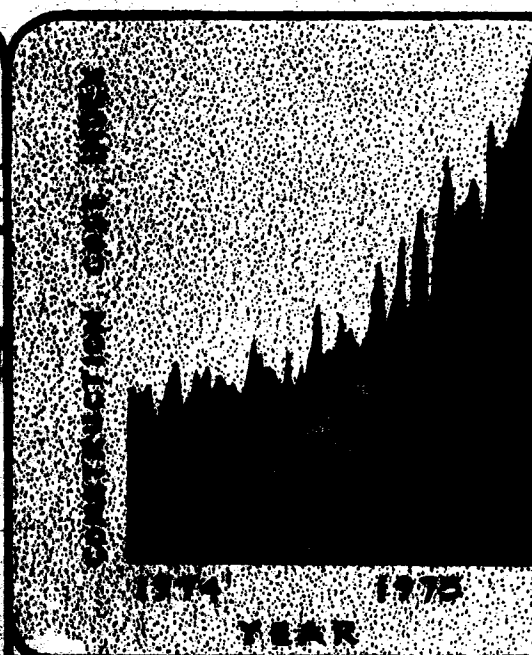
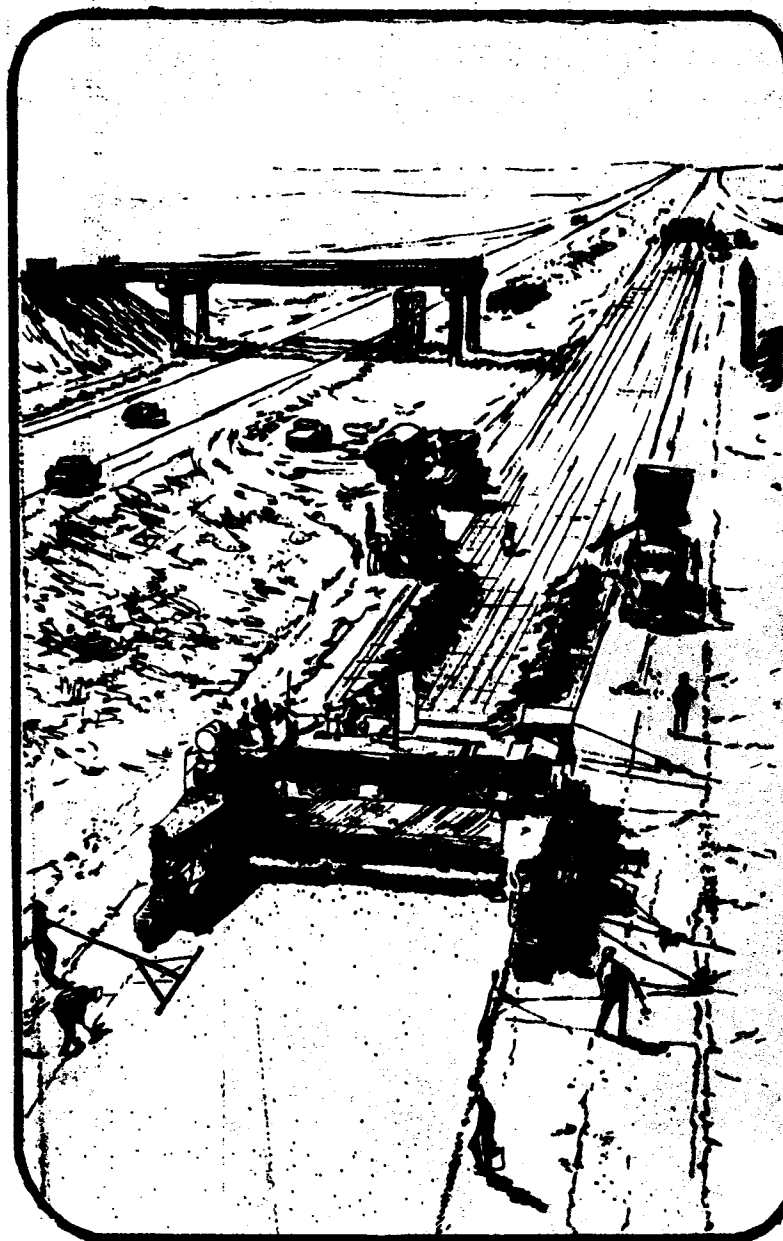


ENGINEERING ECONOMY AND ENERGY CONSIDERATIONS

RECYCLING PAVEMENT MATERIALS

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"ENGINEERING, ECONOMY AND ENERGY
CONSIDERATIONS IN DESIGN,
CONSTRUCTION AND MATERIALS"

TEXAS STATE DEPARTMENT
OF HIGHWAYS
AND PUBLIC TRANSPORTATION

AND
TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY

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RECYCLING OF PAVEMENT MATERIALS

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Introduction

Expansion, rehabilitation and maintenance of the transportation system is dependent upon a supply of aggregate and binder. Projected aggregate requirements for 1985 are more than double the amounts for 1966 and binder requirements are also expected to increase significantly.

The demand for construction aggregates is increasing at a time when sources near urban and other high use areas are being depleted. The quality of available materials is at a low level, and they are becoming unavailable in certain locations because of mining restrictions, environmental protection regulations and/or appreciating land values. Quality aggregates must, therefore, be used selectively; marginal aggregates must be improved and/or utilized, and supplemental aggregate sources must be developed. One possible source of supplemental aggregates is the reuse or recycling of paving materials. Large amounts of rubble, both from highways and from structures, are created annually as old facilities are replaced by new construction. In the past, little, if any, consideration has been given to recycling these materials. Disposal of the old materials has been effected by simply finding a location and hiding the material, usually by burying it. With a growing concern about land pollution and its effects upon the environment, disposal of rubble and other materials by burial is becoming increasingly less attractive and more difficult. Further, the waste of potentially good "rock"

cannot be tolerated, even by an affluent society. As a consequence, serious consideration must be given to recycling rubble whenever possible.

Recycling Paving Materials

A 1971 survey by the Texas Transportation Institute (1) on litter disposal and waste utilization indicated that very few states were giving consideration to the reuse of existing road-bed materials for rehabilitation and reconstruction uses other than for unstabilized base courses. The normal disposal of asphalt concrete or Portland cement concrete seems to have been in landfills or for riprap in some drainage ditches. While the riprap idea has merit, the disposal of these materials in landfill areas is particularly questionable today, due to both the need to conserve our valuable resources and the relatively high cost of providing new construction materials.

A review of published information describing recycling or reuse of paving materials has been completed as part of a cooperative research program between the Texas State Department of Highways and Public Transportation and the Texas Transportation Institute. This review indicates that although several experimental jobs have been performed, only a few of these projects have been reviewed in national publications (2). Table 1 summarizes some of the more important projects.

Two types of construction operations are in general use: in-place recycling, and recycling through a central plant. Untreated and treated materials* have been recycled by these construction operations. Table 2 indicates the various types of pavement recycling operations and the present extent of their use (3). The materials to be recycled include:

*Treated materials are herein defined as chemically bound material.

TABLE 1: RECYCLING PROJECTS

Type of Material Recycled	Location of Project	Aggregate Used For	Remarks	References
Unstabilized base course Stabilized base	Florida	Unstabilized base		No. 4
	Michigan	Stabilized base		No. 5
	Wisconsin	Unstabilized base	No. 8 wire mesh was also processed to meet specifications.	No. 6
	Dist. 8 (Texas) U.S. Highway 84	Asphalt stabilized base		No. 28
Portland cement concrete	Michigan		Predict improved skid resistance and stronger pavement	No. 7
	District of Columbia	Aggregates in general		No. 8
	California	Stabilized base Untreated base	Compaction tests showed crushed rubble is superior to many plant run aggregates	No. 9
	Wisconsin	Untreated	Crushed old paving brick	No. 6
	California	Lean mix cement base	Excess air in mix required use of de-air entraining agent	No. 10
	Dist. 3 (Texas)	Asphalt stabilized base		No. 15
	Dist. 17 (Texas) State Highway 36	Asphalt stabilized base Asphalt concrete	Some air pollution problems experienced	No. 11
	Dist. 4 (Texas) U.S. Highway 54	Asphalt stabilized base Asphalt concrete seal coat	Old airfield pavement utilized	No. 12
	Dist. 4 (Texas) U.S. Highway 60	Asphalt concrete seal coat	This aggregate was produced at a cost less than conventional aggregate	No. 13
	Louisiana		Old pavement was broken, sealed, and overlaid	No. 16
Asphalt concrete	California	Stabilized base	Metradon pulverizer utilized	No. 18
	Indiana	Asphalt stabilized base	Some air pollution problems experienced	No. 22
	Iowa	Asphalt stabilized base		No. 6

CONTINUED

TABLE 1: RECYCLING PROJECTS
(CONTINUED)

Type of Material Recycled	Location of Project	Aggregate Used For	Remarks	References
Asphalt concrete (continued)	Utah	Asphalt concrete surface course	Some air pollution problems experienced	No. 27
	Massachusetts	Base material for runway	15% cost savings over conventional methods	No. 17
	Nevada	Asphalt concrete surface course	Uses new plant which eliminates air pollution	No. 23
			Substantial fuel and materials savings - reduced oxidation of asphalt	No. 24
			No environmental problems	No. 25
			Very little difference in recycled and new asphalt concrete	No. 26
	Dist. 21 (Texas)	Asphalt concrete surface course	Drum mixer used	No. 14
	Dist. 8 (Texas)	Asphalt stabilized base and asphalt concrete	Air pollution problems encountered with both conventional and drum mixer plants	No. 28
Dist. 8 (Texas)		Cold process	No. 21	

TABLE 2: RECYCLING OPERATIONS

FROM	TO	CONSTRUCTION OPERATION	EXTENT OF USE	IMPLEMENT	ENERGY REQUIRED	RELATIVE COST
Untreated Base and/or Subbase and Thin Surface	Untreated Base Treated Base Untreated Base Treated Base	In-Place	Common	Yes	Low	Low
		In-Place	Common	Yes	Low	Mod.
		Central Plant	Rare	Yes	Mod.	High
		Central Plant	Rare	Yes	High	High
Treated Base and/or Subbase and Thin Surface	Untreated Base Treated Base Untreated Base Treated Base	In-Place	Common	Yes	Mod.	Mod.
		In-Place	Common	Yes	Mod.	Mod.
		Central Plant	Rare	Yes	Mod.	High
		Central Plant	Rare	Yes	High	High
Asphalt-Aggregate Surface Mixture	Untreated Base Treated Base Untreated Base Treated Base or Surface	In-Place	Common	Yes	Low	Low
		In-Place	Common	Yes	Mod.	Mod.
		Central Plant	Limited	Yes	Mod.	High
		Central Plant	Rare	Yes	High	High
P.C.C. Surface	Untreated Base Treated Base Untreated Base Treated Base or Surface	In-Place	Limited	Yes	Low	High
		In-Place	Rare	Probably	High	High
		Central Plant	Limited	Yes	Mod.	High
		Central Plant	Limited	Yes	High	High
Existing Base and/or Subbase and Thin Surface Plus New Material	Untreated Base Treated Base Untreated Base Treated Base	In-Place	Limited	Yes	Mod.	Low
		In-Place	Limited	Yes	High	Mod.
		Central Plant	Rare	Yes	Mod.	High
		Central Plant	Rare	Yes	High	High
Heater-Planer		In-Place	Common	Yes	High	Mod.
Heater-Scarifier		In-Place	Common	Yes	High	Mod.
Heater-Scarifier-Remix		In-Place	Common	Yes	High	Mod.

1. Unstabilized base (subbase) and thin surfacing material,
2. Stabilized base (subbase) and thin surfacing material,
3. Asphalt aggregate surface mixtures,
4. Portland cement concrete surface mixtures, and
5. Mixtures of existing base (subbase) thin surface and new material.

The use of the recycled materials include untreated base (subbase), treated base and surfacing materials. In addition to the extent of present use, an estimate of whether the process is implementable, together with an assessment of the energy required to utilize the process and the relative costs, is presented in Table 2. The assessment of energy requirements and costs are relative to other items within this table. Heater-planer, heater-scarifier, and heater-scarifier-remix operations have been utilized in many states and are included in this Table although they are not discussed further in this report.

A brief discussion of projects, grouped according to the materials utilized for recycling as outlined above, follows.

Unstabilized Base Courses

Maintenance forces commonly remove and replace existing surfaces, bases, subbases, and subgrades where localized failures occur in the pavement. Certain of these materials can be recycled, and thus, the maintenance forces are faced with a decision as described in Figure 1. The failed surface, base, subbase and/or subgrade area may be removed, and (a) replaced with a better quality material, (b) replaced with an unstabilized material that has been stabilized with lime, cement, or asphalt, or (c) the in-place material may be recycled by a method or combination of methods shown in Figure 2. Cement is often used as a stabilizer for maintenance type repairs of bases and subbases. The quantity of cement varies but about one-half sack per square

Figure 1
Recycling of Base Materials

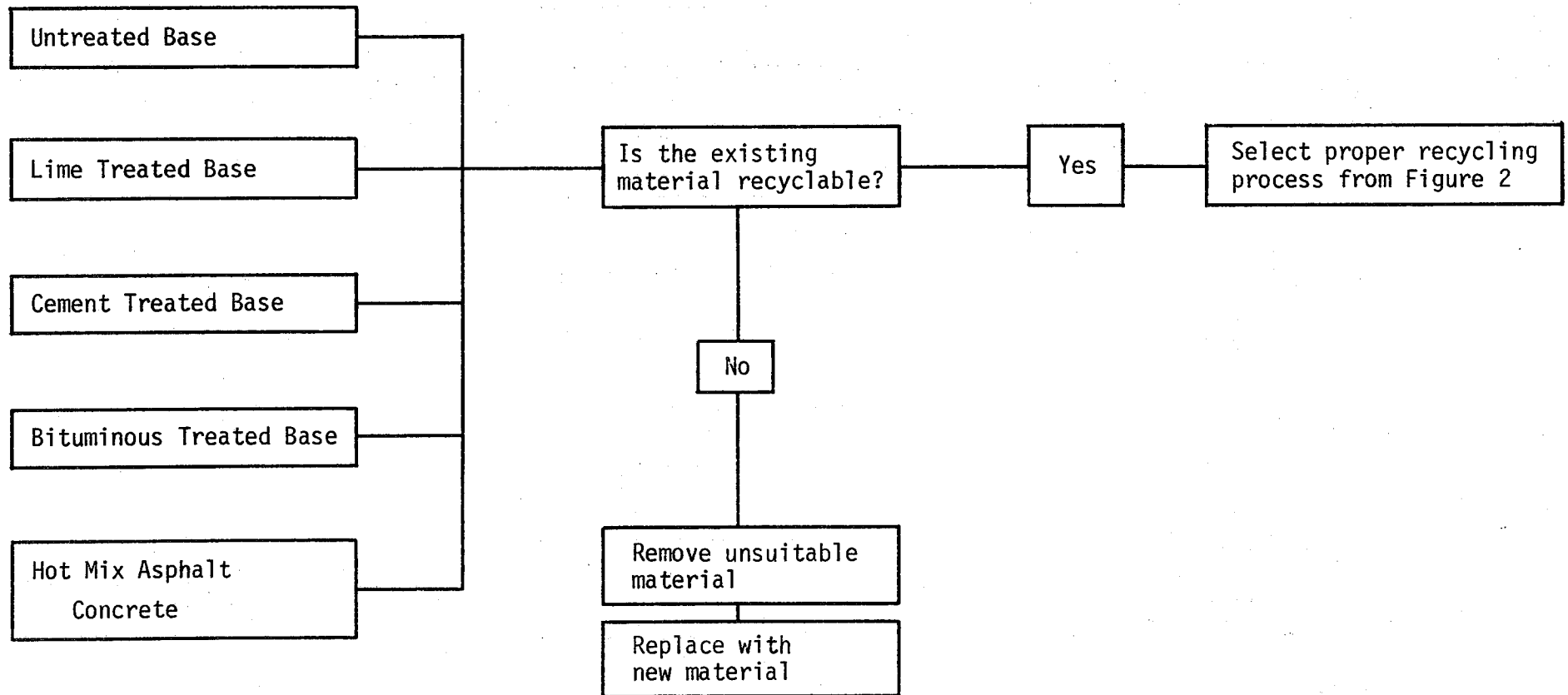
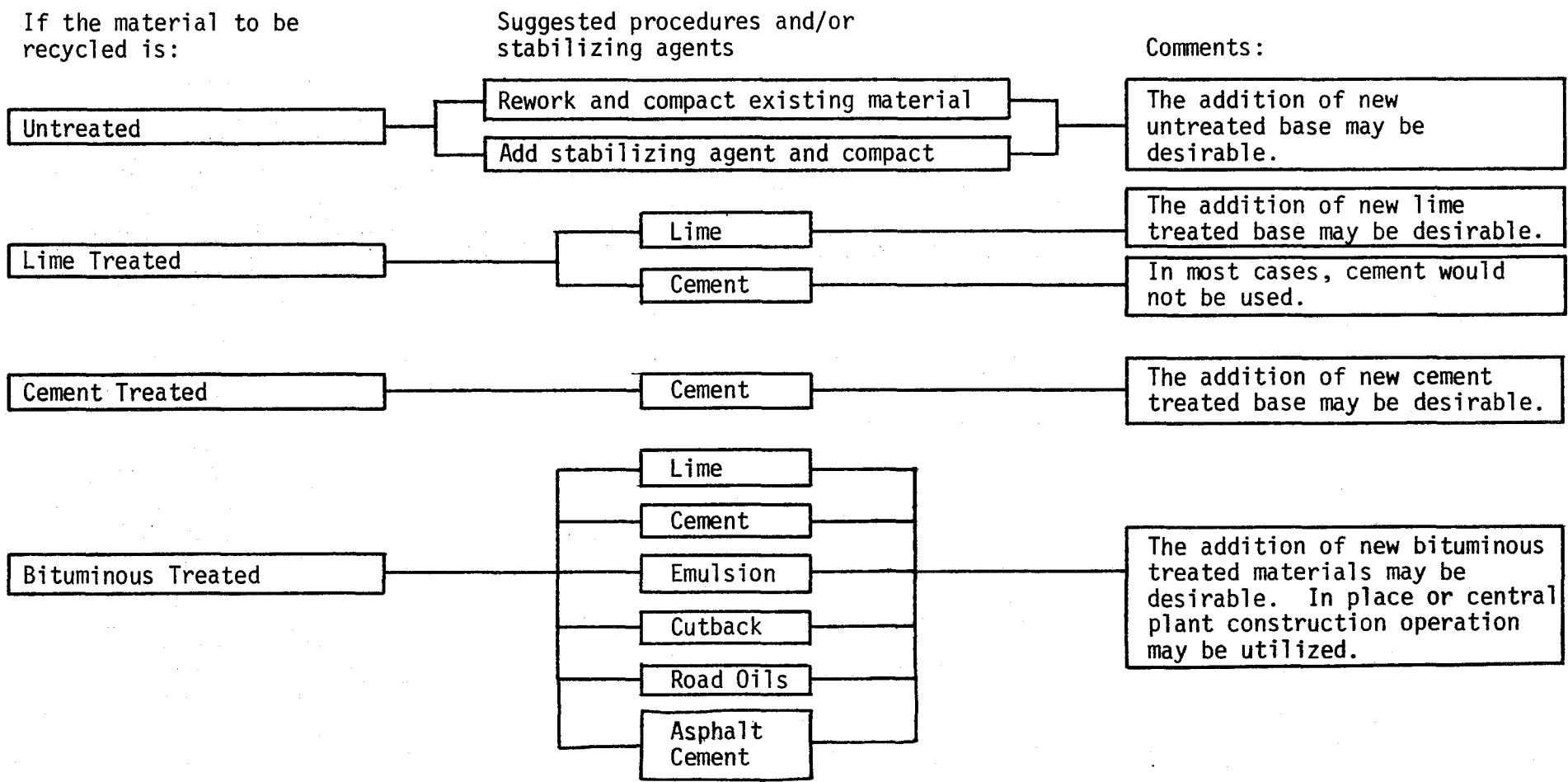


Figure 2
Possible Recycling Methods



yard (for a 6-inch depth) is common. The advantage of this type of repair is that in-place materials can be utilized, thus reducing transportation, handling, and aggregate costs.

Reworking of bases on projects other than "spot" maintenance has also been practiced. One such operation was performed in Florida. The contractor removed the existing base, a 10-inch thick layer of lime rock, and stock-piled it. The subgrade was reworked and the old untreated base put back in place and compacted. This recycled base was then covered with two 5 1/2 inch layers of new lime rock. The surface was then primed and 3 inches of hot-mix placed (4).

Untreated bases may be stabilized in-place by the addition of a stabilizing agent such as asphalt emulsion. The Michigan State Highway Department has stabilized some existing untreated material with emulsion. One project was performed on a 2400 ft. section of U.S. Highway 131. The existing material was removed to a depth of 4 inches and spread evenly over the adjacent lane. Two percent emulsion was added. Mixing of the emulsion and the aggregate was accomplished by alternating asphalt application and blade mixing. After each application of emulsion, the material was mixed and the top inch bladed off and windrowed. This process was repeated until all the aggregate was treated and windrowed. The surface of the subbase was primed and the treated materials replaced. Compaction was performed using rubber-tired and steel wheel rollers. This emulsion treated base was primed and four and one-half inches of asphaltic concrete surface was placed. Performance of this recycled base has been good (5).

Stabilized Base Courses

Localized maintenance repairs of stabilized bases have been practiced by many states. The removal and replacing or reworking of stabilized base

courses under most conditions are more difficult than with unstabilized bases. Examples of procedures utilized by several agencies are given below.

Wisconsin--Several recycling projects have been performed in Wisconsin since 1972. Three miles of State Highway 13 in Adams and Woods counties was recycled in 1973. This roadway consisted of 8 inches of soil-cement base and 13 inches of bituminous surface material. Approximately half of the section had No. 8 wire mesh placed directly on the soil-cement base. This roadway was scarified to a 24 inch depth using a tractor with a single tooth ripper. The scarified pavement, wire mesh, soil cement treated base, and underlying sand base, was hauled to a crusher and processed to meet the specifications for base material. This recycled material was hauled back to the roadway, compacted, and shaped. A three inch asphalt concrete surface was placed on the prepared base (6).

Portland Cement Concrete

Several states have recycled old Portland cement concrete for use as stabilized and unstabilized bases as well as asphalt concrete surface courses (Table 1). These operations will be described below.

Michigan--A parking lot in Detroit has been paved with a one and one-half inch bituminous base containing crushed glass and used concrete topped by a one inch asphalt concrete wearing surface. This material compacted well and had a good appearance. It is predicted that this pavement will be stronger than ordinary asphalt concrete and have a good skid resistance (7).

District of Columbia--Two Washington, D.C. firms are operating crushing plants which produce usable aggregate products from pavement and building rubble. Large slabs of pavement and structural concrete are broken into smaller portions by a hydraulic breaker; then the material is fed into the

portable crusher. Crushed material is screened to obtain the desired gradation. This recycled material exhibits compaction qualities somewhat better than usual subbase materials (8).

California--A California contractor is operating a crusher to convert asphalt and Portland cement concrete rubble into a usable aggregate. Compaction tests performed on the crushed rubble indicate it is superior to many plant run aggregates (9).

Another operation in California consists of recycling Portland cement concrete and asphalt concrete paving materials for use as aggregates in a lean mix Portland cement concrete base. The salvaged material is run through a combination crusher-screening process. Reinforcing steel and other waste is manually removed, and the material stockpiled. The aggregate is then combined with cement, water, and an air detrainning additive to form a lean concrete with an 8 percent cement content (versus 5 percent for cement treated base). The air content was three and one-half percent and the slump averaged two and one-half inches. The California Department of Transportation reported the "natural" mix, without an air detrainning additive, had 13 percent air. Placement of this lean concrete was accomplished using a Blaw-Knox slipform paving machine. Seven day compressive strengths averaged 450 psi and performance has been excellent (10).

Wisconsin--A recycling project was performed on State Highway 13 in Washburn County and U.S. Highway 2 in Ashland County. The existing pavements, consisting of paving brick, asphalt concrete, and Portland cement concrete was broken by a crane and ball. This material was then processed through a crusher to meet a specified gradation. The resulting product was utilized as a base course on both roadways (6).

Texas--Fifteen miles of State Highway 36 in Burleson County was scheduled

for reconstruction in 1967. The existing roadway which was to be recycled was a lightly reinforced Portland cement concrete pavement with an asphalt concrete overlay. The material was broken with a headache ball and the reinforcing steel cut with cutting torches. After being hauled to a central location, the material was crushed and blended for use as an asphalt stabilized base course and asphalt concrete surface course. At the primary crusher, a workman cut the reinforcing steel. Two other workmen removed loose steel from the material stream as it emerged from the secondary crusher. This steel was sold as scrap, and thus the cost of removing the steel was partially recovered.

In addition to the steel causing problems, the variable amount of asphalt concrete present in the processed aggregate created air pollution problems as well as presenting minor difficulties in establishing binder demand. The asphalt quantity requirements were solved by improved plant control; however, air pollution problems were not satisfactorily solved.

Although extensive economic data have not been provided in this article, it can be stated that the contractor did not lose money by his decision to process and use the old pavement in the new construction. Increased costs associated with rubble processing were incurred. However, these costs were largely offset by savings associated with not having to purchase and transport large volumes of high quality coarse aggregate into the area, not to mention savings related to maintenance of existing highways leading to this job if used as haul roads. Fuel requirements for aggregate drying were reduced considerably (11).

U.S. Highway 54 in District 4 was reconstructed utilizing aggregate obtained from Portland cement concrete. This pavement contained steel only at the joints and was thus removed and crushed with little difficulty.

Aggregate produced from this source was utilized for asphalt concrete surfacing, and for seal coat coverstone on the shoulder. Six and one-half percent asphalt was required with the recycled aggregate to produce the asphalt concrete surfacing which had a Hveem stability of 50. The performance of this pavement has been excellent since its completion in April 1972 (12).

A second and more recent job in District 4 was finished in February 1974, on 5.5 miles of U.S. Highway 60 in West Texas (13). The project called for the reconstruction of this Hemphill County highway which was an eighteen foot wide concrete pavement of 9-6-9 design. The reinforcing steel in the thickened edge pavement consisted of two 1/2-inch bars along each side with 1/2-inch by 3 foot bars acting as tie bars between lanes. Dowels were placed on all transverse joints.

This type of pavement was readily adaptable to being crushed because a large portion of the pavement does not contain steel. Pavement breakers were used to fracture the pavement into sizes no larger than one square foot. Two men with cutting torches cut and removed the reinforcing steel as a front-end loader removed the concrete from the road-bed.

A portable crushing plant equipped with a jaw crusher, roll crusher, cone crusher and a screening plant were used to process the rubble. As the material was conveyed from the jaw crusher to the screening plant, two men picked a small amount of steel off the belt. Dust pollution around the crusher was controlled by water spray.

Six percent asphalt cement was mixed with the dense graded aggregate for the asphalt concrete surface course. The Hveem stability of this mixture was 51. The aggregate produced from the crushing operation was also utilized as seal coat rock. The contractor for the project felt that he not only

salvaged a valuable resource, but was able to effect a savings by reducing hauling costs and by producing an acceptable product at less cost.

One section of Interstate 30 east of Greenville, Texas has been constructed utilizing old, crushed Portland cement concrete as a granulated base. An automatic pavement breaker was used to break 75,000 square yards of 10-inch non-reinforced Portland cement concrete into 12-inch sections. The sections were loaded along with two inches of the underlying sand base and hauled to a nearby overpass. Here the material was processed through a crusher. This crushed concrete was hauled to the roadway and deposited as the first layer of a base course. Finishing was accomplished utilizing conventional methods. Performance to date has been satisfactory (14).

District 3 of the State Department of Highways and Public Transportation has also recycled Portland cement concrete building rubble. A detour for Kell Boulevard in Wichita Falls was constructed with 300 tons of asphalt stabilized base composed of crushed concrete rubble and field sand. Placement of this base material was accomplished with conventional equipment, and no difficulty was experienced. Although this detour was only temporary, performance was satisfactory (15).

Portland cement concrete can also be recycled in place. A six-inch concrete pavement in Louisiana was broken by an impact hammer and a 50 ton roller. This broken concrete was seated into the underlying wet subgrade by rolling. The broken concrete was then covered with a three and one-half inch hot-mix overlay. Performance of this recycled pavement has been excellent and no structural deficiencies have been observed (16).

Asphalt Concrete

Asphalt concrete surface courses often are broken up and mixed with the existing base in order to strengthen the base. Stabilizing agents are

sometimes added during this process. Operations of this nature are described below.

Massachusetts--The runway pavement at Orange Municipal Airport was scarified and broken up with a traveling hammer mill. This material was mixed with the existing base and compacted. A prime coat was applied to this improved base and a two-inch asphalt concrete surface course was placed. A 15 percent savings over conventional construction was realized on this project (17).

California--Independent Construction Company of Oakland, California recently completed an in-place recycling project on Road 45, a farm-to-market type road that is heavily traveled by trucks. A tractor armed with rippers tore the old pavement into chunks up to 24 inches long and 9 inches wide. A drum type compactor equipped with cutter pads reduced the material to 4 inch size. Next the material was reduced to 1½ inch maximum size by the Metraron pulverizer. This machine, the only one in existence, picks up the material, pulverizes it, and places it back on the roadbed. Four percent lime was added, and the recycled material was compacted. A seal coat was applied, and the road was opened to traffic in December 1974. For the next six months, the road was subjected to heavy truck traffic. In June 1975, an asphalt concrete overlay was placed. At the time of the overlay, no visible blemishes or breaks were apparent in the recycled base (18).

Michigan--Michigan Department of State Highways has completed several projects in which the shoulder of the highway was recycled using in-place stabilization. The first trial sections were placed in 1963.

Many of the shoulders are 1.5 inches of asphalt concrete on a granular base course. The material is pulverized to a depth of 4 to 5 inches and a stabilizer added and mixed in a single pass. Cutback asphalt, emulsified

asphalt, tar, sodium chloride and Portland cement have been used as the stabilizers. Most of the recent shoulder recycling work has been performed with either a medium setting emulsion (MS-2S) or medium curing asphalt (MC-800). A limited amount of laboratory work has been performed to determine properties of the recycled mixture.

Midwest Asphalt of Troy, Michigan is one of several contractors who have performed the shoulder recycling work. These contractors have also recycled several county roadways in the Detroit area utilizing MC-800 and MS-2S as the stabilizers. Pulverization of the existing pavement and untreated base where the asphalt mixture is less than 4 inches is performed with a Koeing in-place stabilization machine with specially designed blades. About 6,000 square yards per 8-hour day is the expected production rate for the pulverization process.

For pavements with asphalt mixtures greater than 4 inches in depth, a three-step operation is required. A ripper-cutter device mounted on a blade is first utilized to size the pavement to about 4 inches maximum size. The 4-inch maximum size material is then bladed to one side and a working platform established. A portion of the 4-inch maximum size material is then windrowed and a Brosse hammermill machine is utilized to pulverize the material in the windrow. The pulverized material is then bladed to the sides and the process repeated until all material has been pulverized. Following pulverization, the recycled material is stabilized. For example, if the recycled material is all asphalt treated material, about 1 gallon of MC-800 is added per square yard for a 4-inch lift. This three-step operation has been utilized for pavements with 6 to 8 inches of asphalt mixtures (19).

In-place stabilization with soft asphalt cement has been performed in the Detroit area. The asphalt cement was heated to 400°F and mixed with the

moist aggregate. A foaming action takes place which helps the asphalt coating process. The Australians have several years experience with this operation (20).

Iowa--A 0.90 mile section of roadway in Kossuth County, Iowa was recycled in April 1975. This pavement consisted of approximately 4 inches of asphalt concrete on a gravel-clay base. A motor grader was used to scarify the pavement. Chunks of pavement were further broken up by a tractor equipped with compactor wheels. This material was hauled to the plant site where it was crushed to a maximum size of 2 inches.

After the pavement had been removed, the gravel-clay base material was scarified to a 4-inch depth over one-half of the width of the roadway. This material was windrowed, moved, and stockpiled on top of the other half of the unscarified gravel-clay base. A motor grader was then used to cut the excavated half of the roadway down uniformly one foot and place the excavated material on the foreslopes. Compaction of this material was accomplished using sheeps-foot rollers. This process was repeated on the other half of the roadway resulting in 1500 tons per mile of salvaged gravel-clay base. The salvaged material was re-laid, compacted, and utilized as a subbase material.

After the gravel-clay subbase material was in place, the crushed pavement was recycled. Mixing was accomplished by using a 10 by 30 foot drum mixer with a low efficiency wet wash. This mixer had an asphalt line inside the drum and introduced 3.5 percent asphalt by weight into the old pavement which contained 3.7 percent residual asphalt. To reduce the resultant smoke, 3 percent moisture was added to the incoming pavement material. Production was maintained at 275-300 tons per hour with a mix temperature of 225°F. Thirty percent limestone was added to the mixture. The resulting

mix was laid as a base course at a thickness of 4.5 inches. Placement was accomplished utilizing conventional equipment. This recycled material was surfaced with a 3-inch layer of standard asphalt concrete (6).

Texas--Another approach to in-place recycling of asphalt concrete is cold recycling. Division 9, Materials and Research, and District 8 of the State Department of Highways and Public Transportation have performed some preliminary tests relating to rejuvenating hardened asphalts. Results of these tests indicate that a 20 penetration asphalt can be rejuvenated to a 70 penetration by the addition of a softening agent. This softening agent is an asphalt oil which softens the asphalt and decreases the viscosity. The major problem with cold recycling is that uniform breaking of the pavement is difficult to obtain. This results in inadequate mixing with the softening agent. However, results of tests indicate that good coverage can be obtained by using an emulsion of asphalt oil and water (14).

District 8 personnel of the Texas State Department of Highways and Public Transportation have recently completed an in-place recycling project. In October 1975, approximately 1500 feet of U.S. Highway 277 south of Abilene, Texas was recycled in-place. This highway consisted of a limestone base, a two or three course surface treatment, 2-inch asphalt concrete overlay, a seal coat, another hot-mix asphalt concrete overlay, and an additional seal coat. An average asphalt mixture thickness of 4.5 inches existed on this facility.

A D-7 Caterpillar dozer armed with a ripper was used to break up the asphalt pavement. The tracks of the dozer were used to reduce the pavement chunks to a maximum dimension of 14 inches. After ripping, the material was bladed into a 3 cubic feet per linear foot windrow. Water and Reclamite, a softening agent, were added to the windrow to control dust and allow some

mixing of the Reclamite. A Pettibone P-500 traveling hammermill was utilized to pulverize the material. The hammermill contained twenty-four rotating hammers, weighing 60 pounds each, and a power unit. The hammermill was pulled by a front-end loader. Maximum production for this equipment is about 200 tons per hour. Two passes of the hammermill were utilized to pulverize the pavement. After pulverization, the material was bladed to the side of the roadway and the next windrow of broken pavement was prepared for pulverization. After an entire lane was pulverized, a conventional in-place asphalt stabilization process was utilized. Asphalt emulsions, blended with water on a 1-to-1 basis, were utilized for this operation. A Pettibone SM-780 in-place stabilization machine was used to mix the recycled material and emulsion. This machine can mix to a depth of 16 inches. Following this operation, the stabilized material was laid with a blade and compacted with a self-propelled steel wheel vibratory roller. A surface course of hot-mixed, cold-laid material was laid over the recycled material to provide a smooth surface (21).

In the last few years, recycling of asphalt concrete mixes has been accomplished by removing the material from the roadway, hauling it to a centrally located plant, heating, remixing, and replacing it. These operations are described below.

Indiana--Warren Brothers, a contracting company specializing in production of asphalt concrete and roadway construction, has performed a recycling project in Indiana. A drum dryer was used to produce a recycled material from old asphalt pavement and coarse aggregate. One and one-half percent emulsion was added. Air pollution seemed to be the biggest problem. Warren Brothers feel that the main objective of recycling is to utilize existing plants with minor modifications. They have constructed a laboratory scale

model of a conventional dryer. Results of laboratory tests using the model indicate recycling is possible with conventional dryers, provided temperature control can be maintained (22).

Nevada--Las Vegas Paving Incorporated, which developed the RMI Thermo-matic plant, has been active in the recycling of old asphalt concrete pavement at McCarran International Airport in Las Vegas, on Interstate Highway 10 near Sloan, Nevada, and in Henderson, Nevada. The Thermo-matic plant resembles the conventional drum dryer except for one important exception. Direct contact between the burner flame and combustion gases and the old asphalt concrete is not permitted. This design produces a smoke and fume-free effluent which complies with air pollution requirements.

This recycling operation utilizes asphalt additives, about 1/4 to 3/4 of one percent, to soften the old asphalt. Results indicate that the quality of the recycled hot-mix is identical to that of asphalt mixes made with virgin materials (23, 24, 25, 26).

Utah--In October, 1975 the Utah Department of Transportation completed an experimental recycling project near Cove Fort, Utah. This project involved the recycling of approximately 450 tons of pavement material removed from Interstate 15 near Anderson Junction. The pavement consisted of 0.75 inches of plant mix seal containing 6.6 percent asphalt cement and 1.5 inches of surface course containing 4.4 percent asphalt cement. This material was scarified and hauled to the drum dryer plant near Cove Fort. The material was further broken down by the tracks of a dozer and processed through a drum dryer plant where a softening agent was added. Two different percentages of softening agent were utilized, 1.3 percent and 1.0 percent by weight of mixture. Approximately 3 percent water was also added. The resulting mixture was laid with conventional equipment to form a temporary connection between

Interstate 70 and Utah Highway 4 near Cove Fort (27).

Texas--In the early part of 1974, the State Department of Highways and Public Transportation Engineers decided to use a portion of the asphalt concrete removed from U.S. Highway 83 in McAllen, Texas and recycle it as an experimental project. The asphalt concrete was removed in the conventional manner using a headache ball, rippers, and front-end loaders. It was hauled to the contractor's plant site (which was also at his raw aggregate source) and processed through a primary crusher to approximately 2-1/2 to 3 inches top size. The material was then run directly into a drum dryer plant. Preliminary and cursory laboratory analysis indicated that 1 to 1-1/2 percent of additional asphalt (AC-20) would probably be sufficient, but it turned out about 2 percent (AC-20) was required to get the desired mix characteristics. The material coming from the plant had the appearance of a normal mixture and its workability was very similar. This material was hauled to a roadside park on U.S. Highway 281 in North Hidalgo County and placed next to a conventional surface mixture for future observations. Unfortunately, the traffic count on this will be rather low so it will be some time before it is known how it will perform under traffic. Air pollution was not a problem on this operation (14).

In the spring of 1975, a 1.4 mile section of U.S. Highway 84 was recycled on an experimental basis by District 8 of the State Department of Highways and Public Transportation. This section consisted of a hot-mix asphalt concrete surface on a flexible base. After the material was scarified, two methods of crushing the rubble were used. The first material was removed and hauled to a primary crusher and processed. A conventional pugmill plant was used to recycle this material. Various amounts of new asphalt were added. It was determined that the addition of one-half of one percent

asphalt by weight to the recycled pavement produced a material with a good consistency. However, this recycled base did not contain enough asphalt to withstand the action of traffic and raveling occurred.

The second crushing method employed consisted of an in-place crushing operation using a tractor drawn grid roller. This process allowed the contractor to insert moisture into the material to obtain a more uniform moisture content. A 2 1/2-inch screen was positioned on the old cold feed conveyor to remove any large size chunks of pavement before processing in the drum dryer plant. Five different methods of operation were tried. The first trial consisted of 20 percent new base material and 80 percent recycled pavement with the addition of 5 percent by weight of asphalt emulsion. This mixture laid well and had all the appearances of a successful mix. The second trial consisted of 50 percent new base material, 50 percent recycled pavement, and 6 percent asphalt emulsion by weight. This mixture was placed on the roadway with no difficulty. The third process consisted of 60 percent new base material, 40 percent recycled hot-mix, and 6 percent AC-10 asphalt by weight. This mixture produced excessive dust and required the addition of water. Placement of this mixture was accomplished with little difficulty. The fourth mixture tried consisted of 70 percent raw base material, 30 percent recycled base material, and 7 percent AC-10 asphalt by weight. This mixture produced a large quantity of smoke but was placed with a minimum amount of difficulty. The final trial was composed of 100 percent recycled pavement and 4 percent AC-10 asphalt by weight. This mixture did not have a good consistency and placement was difficult.

The major problem encountered in this experimental operation was air pollution. The pugmill plant was equipped with a bag house. This however could not remove the "blue smoke" produced by exposing the asphalt rich old

pavement to direct flame. The drum dryer plant was equipped with a water bath. This also was unable to remove the smoke from the exhaust stack. Temperatures as low as 200°F were maintained in an effort to reduce this smoke (28).

Texas Recycling Conference

A conference on pavement recycling was held on September 4, 1975 in Austin by the State Department of Highways and Public Transportation. The purpose of this conference was to summarize the experience gained by recycling operations both in Texas and throughout the United States as well as point out research needs in the area of pavement recycling. Representatives from Districts 1, 3, 4, 5, 8, 11, 13, 14, 15, 16, 17, 20, 21, 22, and 23, as well as representatives from Divisions 5, 6, 9 and 10 of the Austin office, attended the meeting. The review of recycling projects presented above is in part based on the results of this conference. Particular problems of concern to those present at the conference are discussed below.

Once a decision has been made that a pavement must be rehabilitated, the engineer is faced with several alternative solutions. For example, satisfactory treatments for a pavement section may be a thick overlay, removal of the pavement and replacement with new materials, or recycling. Recycling may be performed in-place or the material may be removed from the roadway, processed through a central plant and replaced on the roadway with or without additional material. If the decision is made to recycle, the process must be selected and the depth of the recycling operation must be established.

Obviously, the engineer needs detailed information to make the decisions in an energy efficient and cost effective manner. The type of distress occurring in the pavement influences his decision. He must be certain that

the asphalt concrete to be recycled is capable of being recycled to produce a suitable mixture. For example, how hard is the asphalt in the mixture? Can its viscosity be reduced to an acceptable level by use of an additive? How much additive is required? Is the aggregate absorptive and/or water susceptible? Will the resulting mixture have the proper stability, strength and fatigue properties? What methods can be utilized to design the recycled mixture? How much additional asphalt is required in the recycled mixture? The above questions are only a few of the many that were addressed at this conference.

Based on a review of recycling experience to date, the following research items were identified:

1. Air pollution associated with recycling asphalt stabilized mixtures in hot-mix operation through a central plant was identified as a top priority research item. It was felt that a solution to the problem will require the involvement of agencies and research institutions.
2. Guidelines need to be established that will assist the engineer in his decision-making process concerned with recycling. For example, what types of pavement and materials tests should be performed to determine if a mixture is suitable for recycling?
3. Costs of recycling operations must be established if the engineer is to select the proper rehabilitation alternative. Limited cost data are presently available.
4. Properties of recycled mixtures should be determined and compared with both conventional mixtures and properties of the mixture before recycling. The effect of additives on recycled mixtures is of importance.

5. In-place recycling equipment needs to be improved to reduce equipment maintenance costs. Pulverization equipment is the most critical item in need of improvement.

Economics of Recycling

Over the past few years, labor, equipment, and material prices have escalated. As a result, the cost of new construction has increased. Obviously, some means must be developed to offset these increasing prices. Recycling can be one method of alleviating these rising costs.

Michigan--The Michigan Department of Highways has conducted several projects involving the in-place recycling of untreated bases. These recycling operations were conducted utilizing conventional equipment. The cost of recycling one square yard of untreated base material six inches thick is about \$0.80 to \$1.00 (19). This cost is applicable only when no new material or additive is required.

A private contractor in Michigan has altered existing in-place stabilization equipment to recycle asphalt concrete pavements and various types of base courses. The pulverization equipment can process a 6-foot wide by 4-inch deep section at a rate of about 15 to 20 feet per minute. A production rate of about 6,000 square yards is expected per 8-hour day. Prices for this process are 0.85 to 1.00 dollar per square yard plus the stabilization agent (19).

California--Independent Construction Company has recycled several asphalt surfaces by pulverizing and mixing them with the existing base. Prices for the pulverization process range from \$0.67 to \$0.72 per square yard. Their unique Metradox pulverizer has also been used to recycle four-inch asphalt surfaces by stabilizing the pulverized asphalt surface and existing base combination with four percent lime. The price for this operation was \$2.10

per square yard plus the cost of the lime and water. Independent Construction Company estimates that 50 percent of the cost of hauling new rock to the job can be saved by utilizing their recycling method (29).

Nevada--Las Vegas Pavings, Inc. has already begun to take advantage of the cost savings available from recycling asphalt concrete. Utilizing the Thermo-matic plant, they can produce recycled asphalt concrete for \$4.81 per ton. New hot-mix can be produced for \$7.31 per ton. The various components formulating these costs are shown in Table 3. This \$2.50 savings represents a 34 percent savings for the paving industry (24).

As suggested by the Nevada study, a substantial cost savings may be possible by recycling old bituminous mixtures in a hot-mix operation. Asphalt and aggregate costs comprise about 50 percent of the in-place cost of asphalt concrete. About one-half of this 50 percent is composed of aggregate cost while the cost of asphalt makes up the other half. If it is assumed that the average cost of asphalt concrete is 20 dollars per ton, the following savings may be possible.

1. About 1 to 1.5 percent new asphalt cement is required in recycled mixtures. If it is assumed that typical asphalt concrete requires 6% asphalt cement, a cost savings of about \$3.25 per ton can be appreciated or 16%.
2. The aggregate for the recycled mixtures is the old asphalt concrete pavement. The old asphalt concrete pavement must be removed, hauled to the hot-mix plant site, crushed and sized prior to the hot-mix process. The cost of removal, hauling, crushing and sizing should be compared with the cost of purchasing and hauling new aggregate, if one assumes that an asphalt concrete overlay would provide the

per square yard plus the cost of the lime and water. Independent Construction Company estimates that 50 percent of the cost of hauling new rock to the job can be saved by utilizing their recycling method (29).

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TABLE 3

COST TO MANUFACTURE NEW ASPHALTIC CONCRETE 3/4"

<u>800 Ton Per Day Conventional Plant</u>		
		<u>Cost</u> <u>(\$/ton)</u>
Asphalt (5-1/2% average) FOB Las Vegas Rack, Jan. 1974	Cost/ton: \$65.10 tax: 2.28 total: <u>\$67.38</u> x .055	3.70
Rock, sand, and aggregate royalties Plant run through		1.25 <u>2.36</u>
Total cost (FOB Plant)		<u>7.31</u>
<u>Las Vegas Paving, Inc.</u> <u>R.M.I. Method</u> <u>800 Ton per day Plant</u>		
Additional Asphalt (1% average) FOB Las Vegas Rack, Jan. 1974	Cost/ton: \$65.10 tax: 2.28 total: <u>\$67.38</u> x .001	0.67
Softening agent, 1/2% Rock and sand (old AC crushed) Plant run through Plant lease to R.M.I.		0.68 1.00 1.91 <u>0.55</u>
Total cost (FOB Plant)		<u>4.81</u>
Savings/ton = \$2.50		

After reference 24.

same performance as a reconstruction operation. If removal of the old pavement is required, even if new materials are to be utilized, an appropriate comparison should be made.

The crushing operation can be performed either at a central location or on the roadway with hammer mill type equipment such as that used in California or Michigan or by the use of rippers and grid rollers. Cost for removal, haul and crushing can be expected to be about 3 to 4 dollars per ton for hauls of about 10 to 15 miles. Typical cost for new aggregates would be in the range of 4 to 6 dollars per ton depending on the haul. Thus, individual projects must be carefully analyzed prior to establishing an overall cost savings based on aggregate savings.

3. The cost of mixing and placing a recycled pavement may not be identical to that of mixing and placing a new asphalt concrete mixture. The Nevada work indicates that a fuel savings may be possible (24) which may amount to about 30 cents per ton of asphalt concrete.

The desired detailed cost information is presently not available for recycling; however, it appears as if substantial cost savings are possible, particularly where quality aggregates are in short supply and/or a great distance from the point of intended use.

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