ENGINEERING ECONOMY AND ENERGY CONSIDERATIONS

SEAL COAT ECONOMICS AND DESIGN

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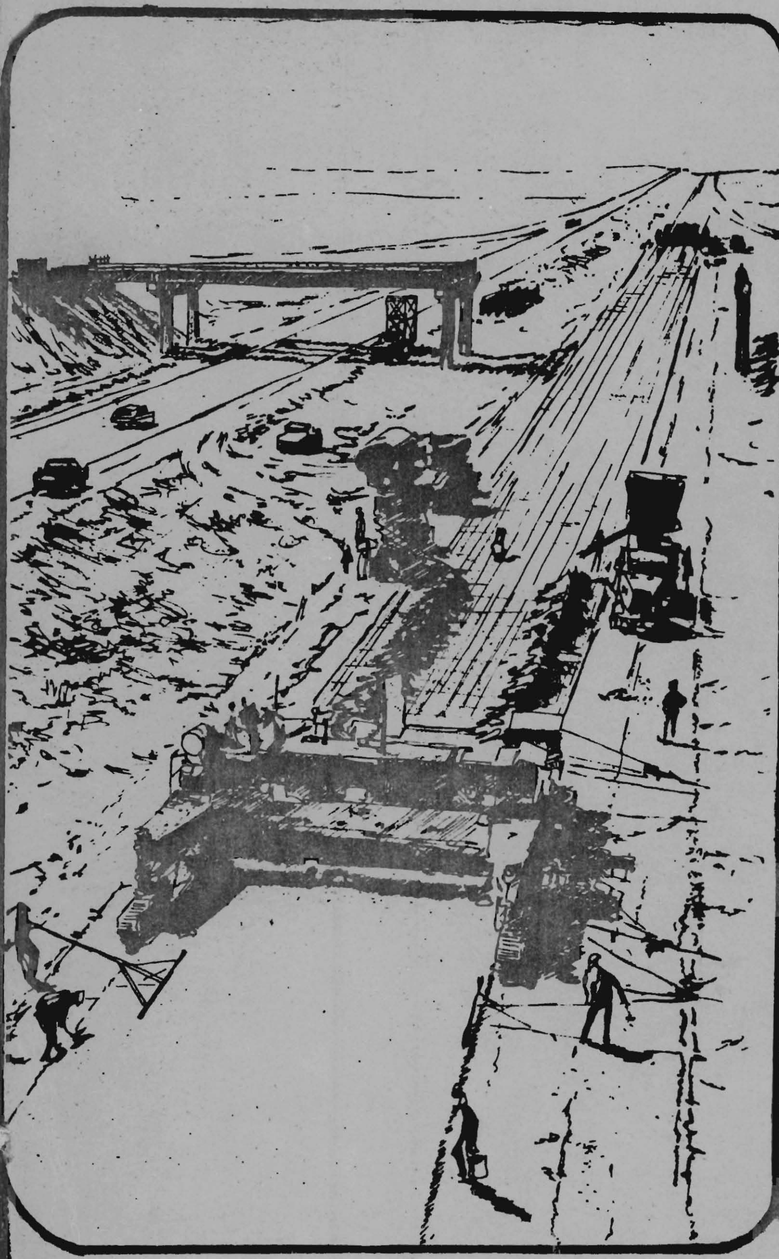

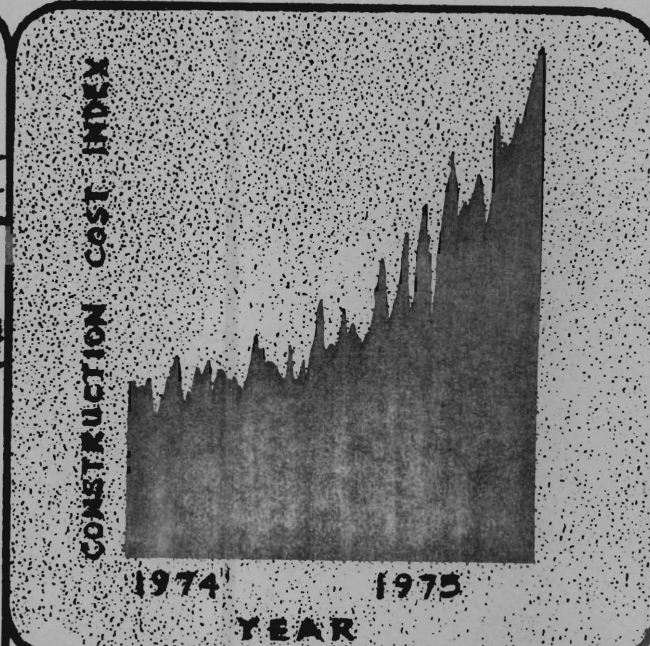

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"ENGINEERING, ECONOMY AND ENERGY CONSIDERATIONS IN DESIGN, CONSTRUCTION AND MATERIALS"

TEXAS STATE DEPARTMENT
OF HIGHWAYS
AND PUBLIC TRANSPORTATION

AND

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY

STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

TASK FORCE ON ENGINEERING, ECONOMY AND ENERGY CONSIDERATIONS

Larry G. Walker, Task Force Chairman and Materials and Tests Engineer

Charles H. Hughes, Sr., Study Contact Representative and Assistant Materials and Tests Engineer

H.L. Arno, Engineer, Secondary Roads

Paul H. Coleman, District Engineer

Wayne Henneberger, Bridge Engineer

Robert L. Lewis, Chief Engineer, Highway Design

Archie J. Sherrod, Chief Engineer, Maintenance and Operations

J.R. Stone, District Engineer

William V. Ward, Urban Project Engineer-Manager

Phillip L. Wilson, State Planning Engineer

Franklin C. Young, District Engineer

Theodore E. Ziller, Construction Engineer

TEXAS TRANSPORTATION INSTITUTE

W. Frank McFarland, Study Supervisor and Transportation Economics and Sociology Program Manager

Jon Epps, Natural Materials Program Manager

Ronald Holder, Transportation Operations Program Manager

SEAL COAT ECONOMICS AND DESIGN

By

William R. Stockton

and

Jon A. Epps

Introduction

Surface treatments* and seal coats** have proven to provide economical surface course alternatives on many highways. The initial economies of such construction as opposed to thick asphalt concrete surfaces are readily apparent and long term analysis also shows savings in many cases.

Established engineering principles can reduce performance problems which sometimes occur such as poor skid resistance, streaking, flushing or bleeding, loss of aggregate and poor bond between the existing surface and new surfaces. It is of utmost importance that engineering administrators evaluate the seal coat surface treatment alternate when applicable and also recognize that failure to use known design considerations and good construction practices can quickly nullify potential economies.

This report reviews engineering guidelines that provide desired surface treatments and seal coats. Specific items discussed include identification of roadway sections suitable for surface treatment and seal coat surfaces, material selection guideline, design methods and construction control guidelines. A method is also presented which allows the engineer to make an

* A surface treatment is a bituminous surface that results from one or more successive alternate applications of bituminous binder and cover stone to a prepared consolidated gravel, crushed stone, stabilized soil or similar base.

**A seal coat is a bituminous surface that results from one or more successive alternate applications of bituminous binder and cover aggregate to an existing paved surface.

economic comparison of various aggregate types and gradations, provided asphalt and coverstone costs are known, and the performance period can be estimated. As will be pointed out in the report, the engineering based estimate of performance period is of critical importance for proper economic considerations to be established.

An understanding and use of the principles presented here will provide extended performance and enhance the possibility of successfully completing the construction operation, thereby reducing the annual cost of surface treatments and seal coats.

Uses of Surface Treatments and Seal Coats

Surface treatments are utilized to provide an inexpensive permanent type of bituminous riding surface. Properly designed and constructed surface treatments will provide an effective seal against the intrusion of water and will reduce the dusting and rutting problems associated with unsurfaced roadways.

Experience has shown that surface treatments should be utilized as a riding surface only on roads with bases that can support the imposed traffic loads. The type of base course, the amount and nature of the traffic, and the environmental conditions in which the roadway must perform should be evaluated by the engineer prior to the selection of a surface treatment as a riding surface.

Seal coats are applied to an existing bituminous surface for the following purposes: seal an existing bituminous surface against the entrance of air and water, enrich an existing dry or raveled surface, provide a skid resistant surface, increase the visibility of the pavement surface at night, reduce tire noise, improve demarcation of traffic lanes and/or attain a uniform appearing surface. Little increase in load carrying capacity is obtained from the additional pavement thickness supplied by the seal coat; however, an effective seal may improve the load carrying ability of a pavement by altering the water content of the materials composing the pavement structure. If a pavement surface shows evidence of traffic load associated cracking (alligator, longitudinal, transverse), a seal coat is only a temporary solution. A thick asphalt concrete overlay or reconstruction is normally required to correct these types of problems.

Rough riding pavement surfaces cannot be improved significantly by the application of a seal coat. Overlays of various thicknesses, spot level maintenance operations, or reconstruction is normally required to restore pavement ride quality.

Seal coats applied to pavements showing signs of non-traffic load associated longitudinal and transverse cracks have proved somewhat effective. Seal coats usually bridge these cracks in a more satisfactory manner than thin asphalt concrete overlays. Other pavement overlay systems, some of which contain seal coats with special binders, are being developed and appear promising.

Pavements demonstrating flushing or bleeding are difficult to repair with seal coats. The bleeding normally migrates through the new seal coat unless the asphalt quantity applied to the roadway can be altered as these spot, flushed areas appear on the roadway. Asphalt concrete overlays have proved to be more effective in reducing or eliminating flushed surfaces. Seal coats utilizing a large maximum size aggregate are suggested, if seals are utilized on flushed surfaces.

Pavements with ruts or corrugations normally must be repaired with an overlay or heater planer. Seal coats are not an effective treatment for these types of distress.

Seal coats have been used successfully on pavements carrying 5,000 vehicles per day per lane in rural areas. The probability of successfully placing a seal coat is, however, greatly increased on roadways carrying lower traffic volumes. The use of seal coats in urban areas where accelerating and decelerating traffic occurs frequently should be approached with caution.

Materials Section

Aggregates to be used as coverstone for surface treatments and seal coats are adequately specified under the following Texas State Department of Highways and Public Transportation specified items (1).

Item 301 - Aggregate for Surface Treatments (Class A)
Item 302 - Aggregate for Surface Treatments (Class B)
Item 303 - Aggregate for Surface Treatments (Lightweight)
Item 304 - Aggregate for Surface Treatments (Precoated) (Class B)
Item 305 - Aggregate for Surface Treatments (Precoated) (Class A)

Precoated aggregates have been utilized to reduce aggregate dust, to reduce automobile glass damage due to flying stone and to promote bond with the asphalt. Lightweight aggregates have been utilized since 1961 in Texas to provide pavements with a high coefficient of friction, color contrast and to reduce or eliminate glass damage due to flying stone. Selection of the specification item for designation of coverstone has been based largely on availability and cost of materials, materials performance and skid resistance considerations. A preferred natural aggregate is that specified under Item 301 with a one sized gradation. The one size gradations allow additional asphalt to be used effecting a more positive seal and reducing the likelihood of aggregate loss and the associated resulting automobile glass damage and bleeding surfaces.

As mentioned above, skid resistance is an important if not the controlling factor in selecting the type of aggregate to be used as a surface treatment or seal coat coverstone. It is important that the aggregate have an adequate initial coefficient of friction, and that an acceptable coefficient is maintained under the traffic imposed on the facility. Polish values, as determined by test method Tex-438-A, can be utilized to select acceptable aggregates for individual projects.

The preferred particle shape for coverstone is cubical or tetrahedral. Flat or elongated particles should be avoided. Rough surface textures are also normally preferred.

The selection of the maximum size of aggregate is normally based on economic, materials availability, traffic volume and skid resistance considerations. Large maximum size coverstones require larger amounts of asphalt than small maximum size coverstones. For example, a Grade 5 coverstone with a maximum size of one-quarter inch requires approximately 0.20 gallons of asphalt per square yard while a Grade 3 coverstone with a maximum size of five-eighths inch requires approximately 0.40 gallons of asphalt per square yard. It is evident that Grade 3 coverstone will provide a more effective seal because of the thickness of the applied asphalt and that field variations in applied asphalt quantities which are of the order of 0.06 gallons per square yard are much more critical for Grade 5 than for Grade 3 coverstone.

It is a common practice in the state to select the larger maximum size aggregates for the high traffic volume facilities. Grade 3 or 4 is normally utilized on these facilities. In additions, the larger maximum size coverstone improves pavement surface drainage and thus reduces the potential for hydroplaning. Tire-pavement noise may, however, be higher with Grade 3 aggregates, under certain conditions.

Asphalt

Bituminous binders for surface treatments and seal coats must be fluid enough at the time of spraying to allow uniform application, fluid enough at the time the cover aggregate is applied to develop rapid wetting and fast initial adhesion between the binder and the aggregate as well as the underlying road surface, and viscous enough to retain the coverstone when the surface is opened to traffic (2, 3, 4).

Asphalt cements, emulsified asphalts and cut-back asphalts, as specified by Item 300 of the Texas State Department of Highways and Public Transportation Standard Specification, are utilized for surface treatments and seal coats. Commonly used asphalt cements are AC-5 and AC-10. AC-5 is often preferred in areas having colder or lower average temperatures, whereas AC-10 is preferred in warmer areas. Also, AC-5 is used for light traffic and AC-10 for heavy traffic. Seal coats placed during cooler weather, especially approaching winter, would influence choice of AC-5 over AC-10. Rapid setting and medium setting anionic and cationic emulsions have desirable properties and are preferred with certain aggregates and for some times of the year. The use of cutbacks should be avoided under most conditions but have been used during the winter when necessary.

Design Method

The design method described below is based on a modification of the original Kearby method which has been utilized by several districts (5, 6). Laboratory tests and calculations required in the design method, together with a method to select the type and grade of aggregate on an economic basis, are given below.

Laboratory Tests:

Dry Loose Unit Weight -- The dry loose unit weight determination shall be made in accordance with Tex-404A, except that the aggregate shall be tested in an oven-dry condition.

Bulk Specific Gravity - The bulk specific gravity shall be made in accordance with Tex 403-A for all natural aggregate and by the test method Tex 433-A for synthetic aggregates.

Board Test - Place a sufficient quantity of aggregate on a board of known area such that full coverage one stone in depth is obtained. A one-half square yard area is a convenient laboratory size. The weight of the aggregates applied in this area is obtained and converted to units of pounds per square yard. Good lighting is recommended and care should be taken to place the aggregate only one stone deep.

Calculations

The quantity of aggregate expressed in terms of square yards of road surface that can be covered with a cubic yard of aggregate and the quantity of asphalt in gallons per square yard can be found as described below.

Aggregate Quantity

$$S = \frac{27W}{Q}$$

Asphalt Quantity

$$A = 5.61E \quad 1 - \frac{W}{62.4G} \quad (T) + V$$

where:

S = quantity of aggregate required, sq. yds. per cu. yd.

W = dry loose unit weight, lbs. per cu. ft.

Q = aggregate quantity determined from board test, lbs. per sq. yd.

A = asphalt quantity, gallons/sq. yd.

E = embedment depth obtained from Figure 1 as follows:

$$E = ed$$

where:

e = percent embedment (Figure 1)

d = average mat depth, inches

$$= \frac{1.33Q}{W}$$

G = dry bulk specific gravity of aggregate

T = traffic correction factor obtained from Table 1

V = correction for surface condition obtained from Table 2

5.61 = (7.48)(9/12), a conversion factor

Note: Asphalt quantities calculated by these methods are for asphalt cement. Appropriate corrections must be made where a cutback or an emulsion is used.

Table 1. Asphalt Application Rate -- Correction Due To Traffic

	Traffic - Vehicles Per Day Per Lane				
	Over 1,000	500 to 1,000	250 to 500	100 to 250	Under 100
Traffic Factor (T)	1.00	1.05	1.10	1.15	1.20

Table 2. Asphalt Application Rate Correction Due to Existing Pavement Surface Condition

Description of Existing Surface	Asphalt Quantity Correction gal/sq. yd.
Flush asphalt surface	-0.06
Smooth, nonporous surface	-0.03
Slightly porous, slightly oxidized surface	0.00
Slightly pocked, porous, oxidized surface	+0.03
Badly pocked, porous, oxidized surface	+0.06

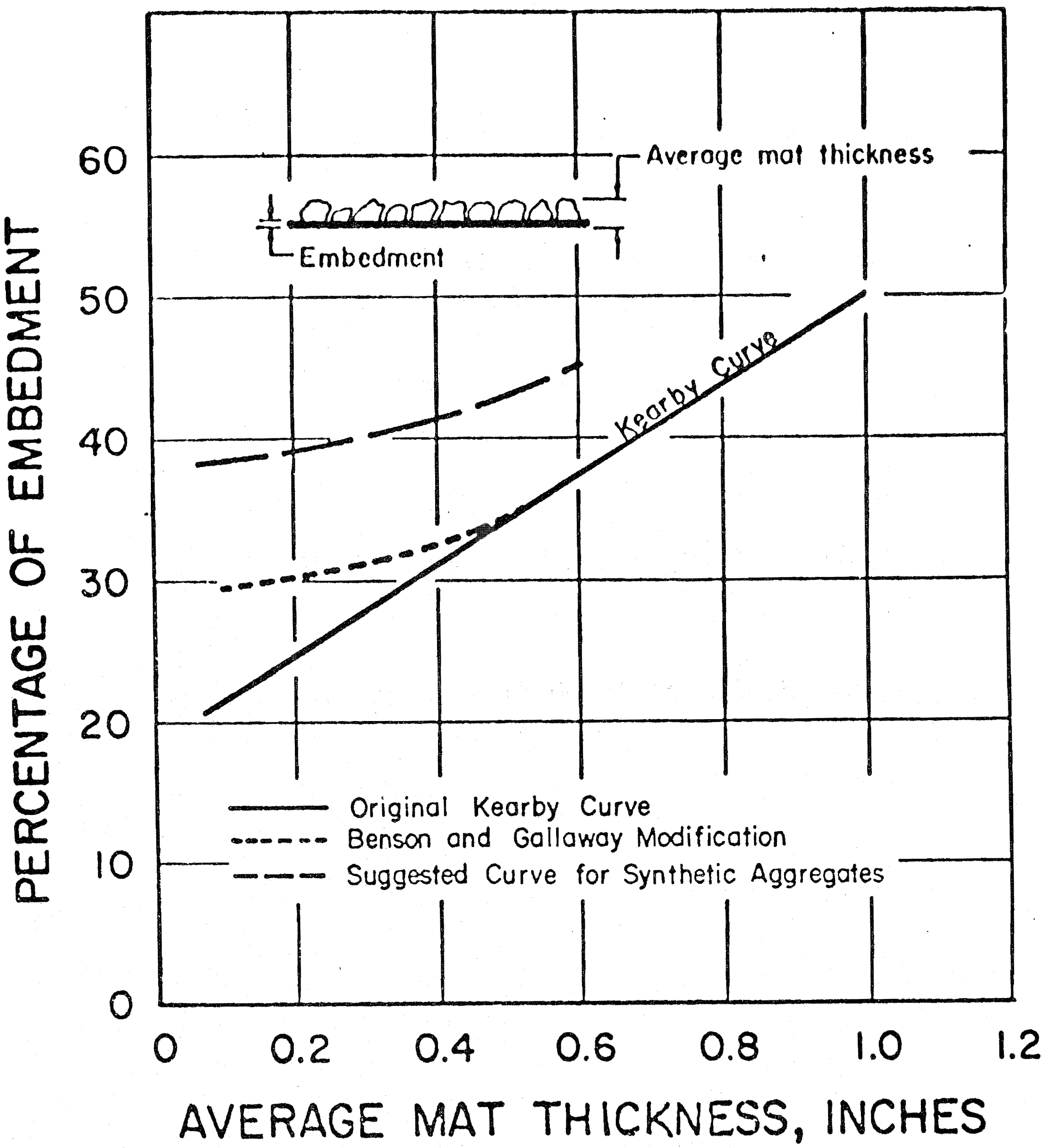


Figure 1. Relation of percent embedment to mat thickness for determining quantity of asphalt (b).

Sample Calculations:

Given:

(W) Dry loose unit weight of aggregate = 52.4 lbs/cu. ft.

(G) Dry bulk specific gravity of aggregate = 1.57

(Q) Quantity of aggregate (board test) = 9.7 lbs/sq. yd.

Traffic = 700 vehicles per day per lane

Roadway Surface Condition = slightly pocked, porous, oxidized

Quantity of Aggregate

$$S = \frac{27W}{Q} = \frac{27(52.4)}{97} = 146 \text{ sq. yds.}$$ (square yards of roadway surface per 1 cubic yard of aggregate)

Quantity of Asphalt

$$A = 5.61E \left(1 - \frac{W}{62.4G}\right) (T) + V$$

$$d = \frac{1.33Q}{W} = \frac{1.33(9.7)}{52.4} = .246 \text{ inches}$$

e = 40 percent from Figure 1 for synthetic aggregates

E = ed = .40(.246) = 0.0985 inches

T = 1.05 from Table 1

V = +0.03 from Table 2

$$A = 5.61\ (0.0985)\quad 1 - \frac{52.4}{62.4(1.57)}\quad (1.05) + 0.03$$

A = 0.30 gallons of asphalt per square yard of roadway surface

If an emulsion with 30 percent water were to be utilized, the quantity of emulsion would be:

$\frac{0.30}{}$ = 0.43 gallons of emulsion per square yard of roadway surface

Economic Analysis

In an effort to provide a basis for comparison of costs associated with various seal coat aggregate gradations and types, nomographs have been prepared and are shown on Figures 2, 3, and 4 for river gravel, limestone, and lightweight aggregate respectively. The river gravel is subrounded, the limestone crushed and the lightweight aggregate is blocky in shape. The gradings for the river gravel and crushed limestone are given in Item 302, while Item 303 specifies the gradations for the lightweight aggregates.

Figures 2, 3, and 4 can be utilized to determine initial in-place costs of a surface treatment or seal coat. Required information includes aggregate costs, asphalt costs, aggregate type, aggregate grade and if the gradation is on the coarse or fine side of the gradation band. Figure 5 was developed to assist in the evaluation of expected annual costs of seal coats. Annual costs per square yard may be determined using initial cost and seal coat performance life. The nomograph is based on an 8 percent compound interest factor. Similar nomographs may be prepared for other interest rates. Examples of how these nomographs can be used are given below.

Effect of Gradation and Type of Aggregates on Cost

Data for two examples will be developed to illustrate the effect of gradations and type of aggregate on cost. Example 1 assumes that Grades 3, 4, and 5 river gravel are available at an in place cost of $15.00 per cubic yard, and asphalt at $0.50 per gallon ($120 per ton). Example 2 assumes that Grade 4 river gravel, limestone and light weight aggregate are available at $15.00 per cubic yard and asphalt is the same price as above.

Figure 2. In-Place Cost of River Gravel

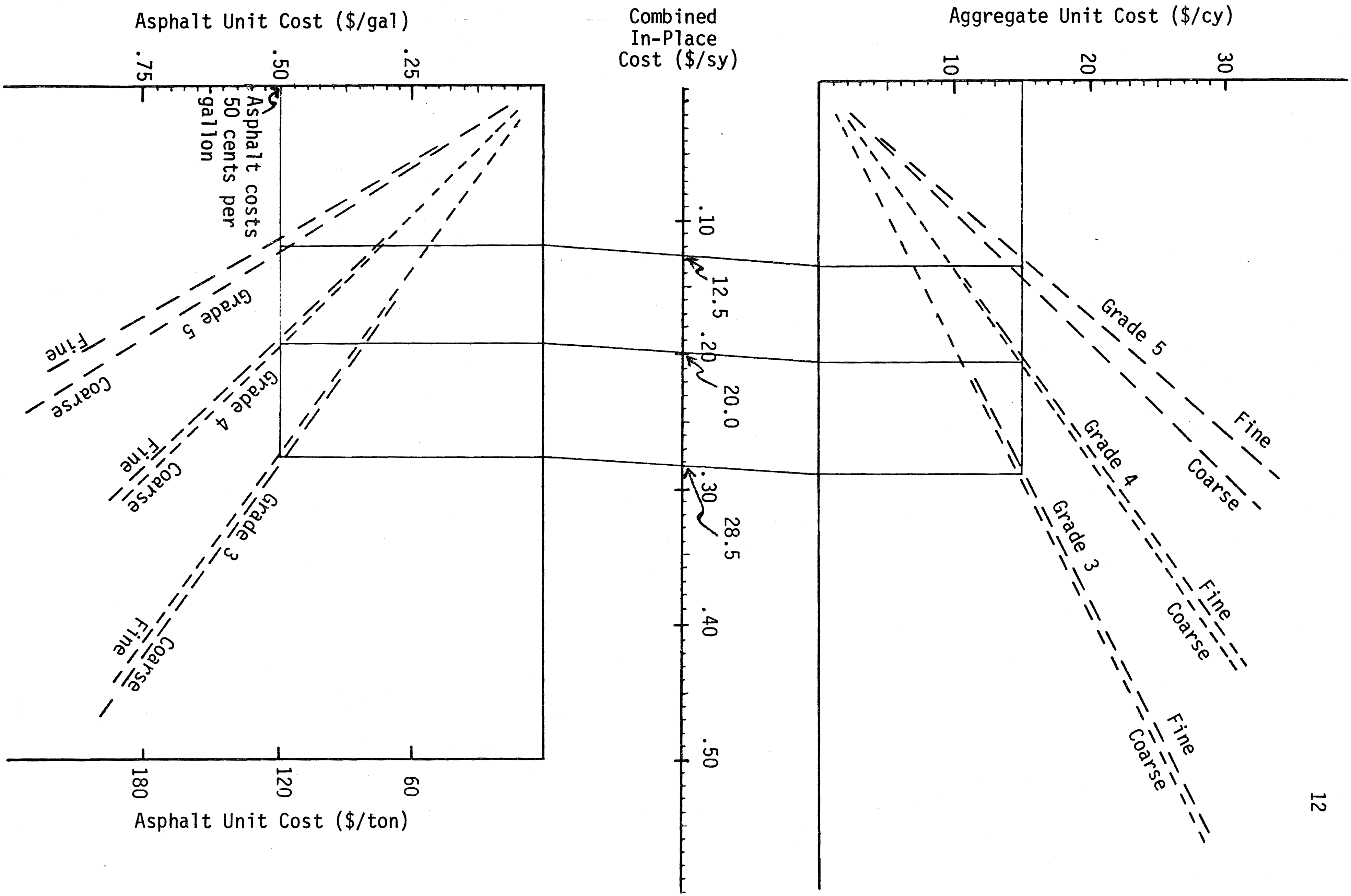


Figure 3. In-Place of Limestone

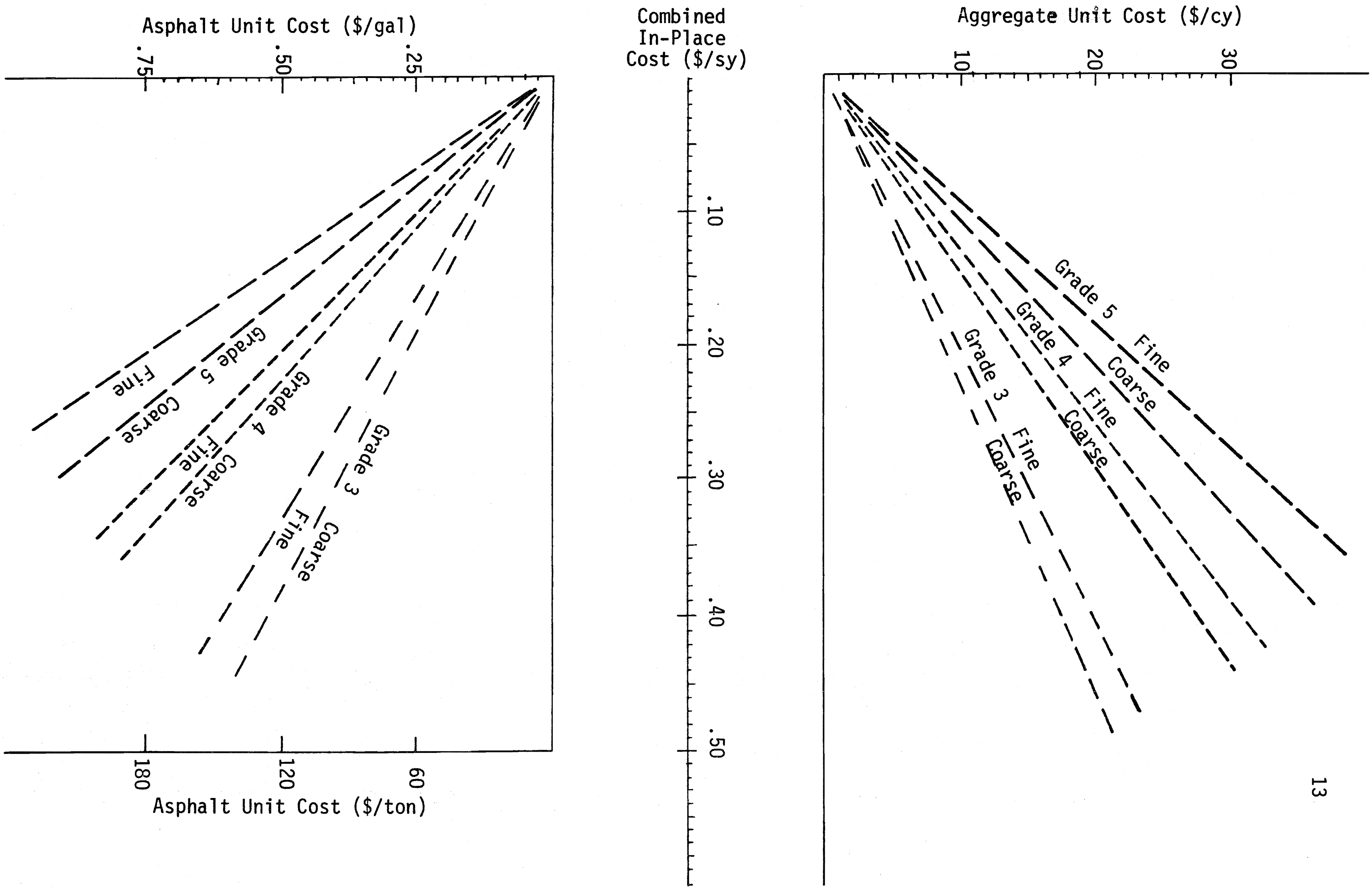


Figure 4. In-Place Cost of Lightweight

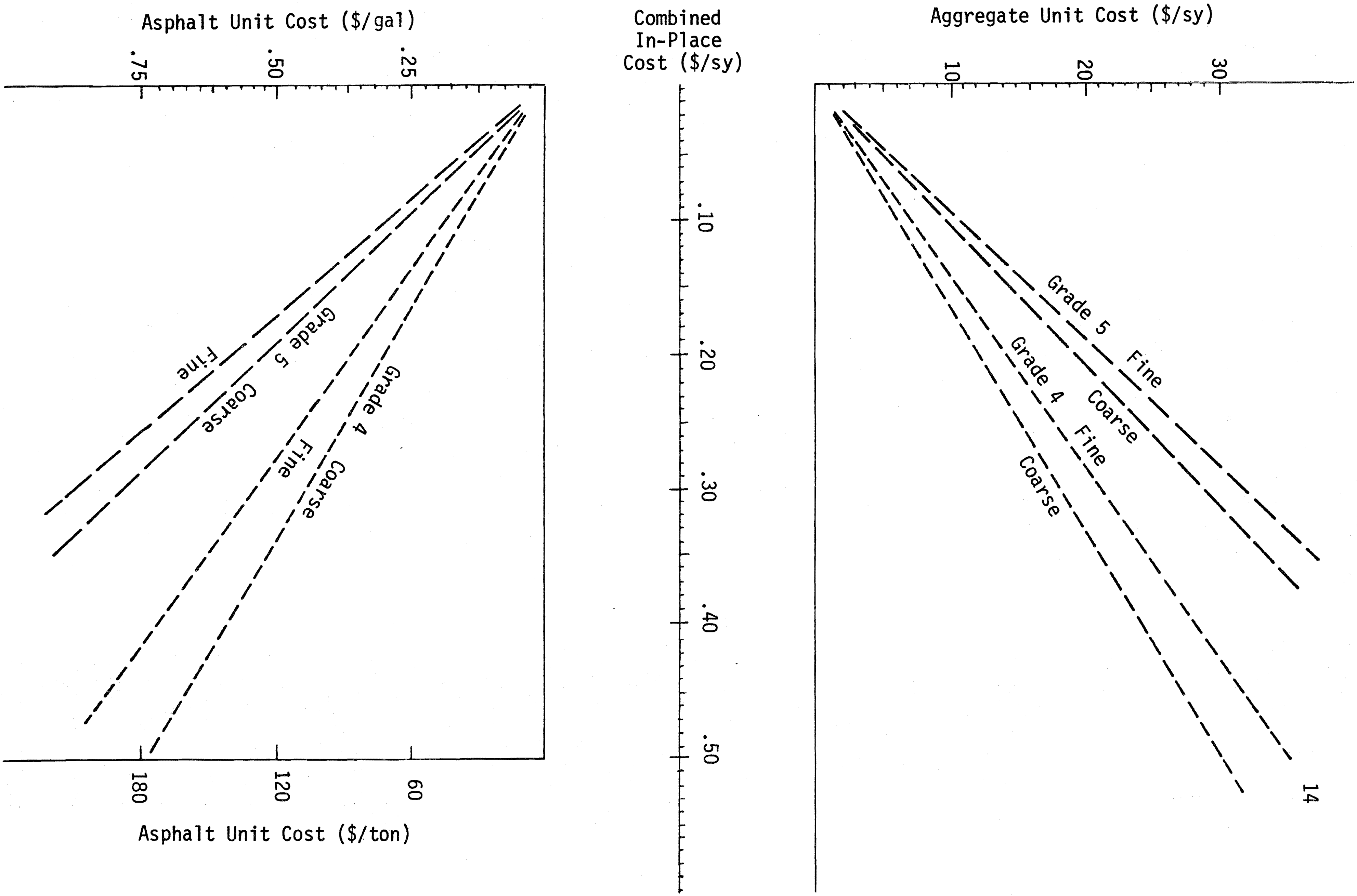
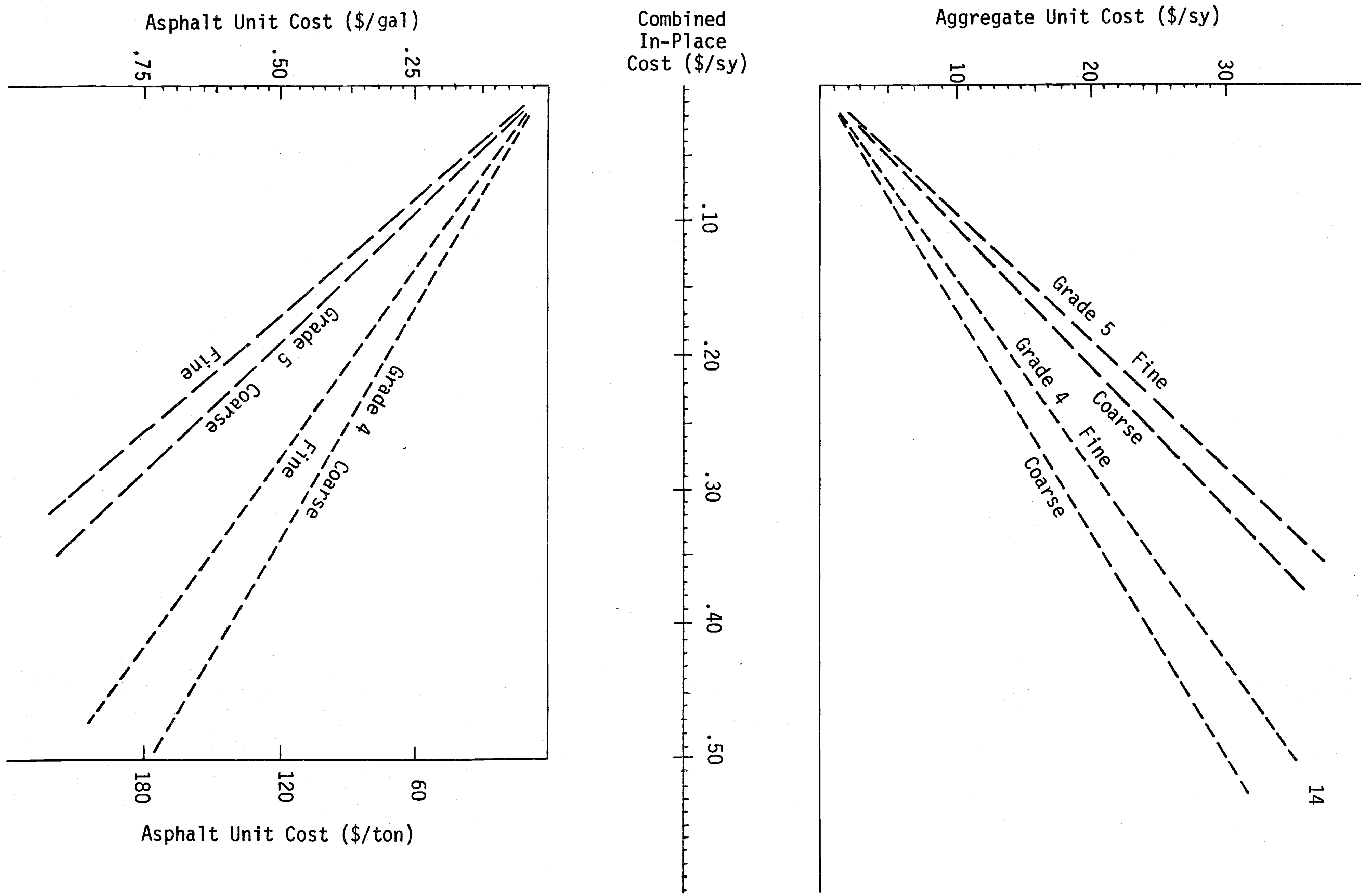


Figure 4. In-Place Cost of Lightweight



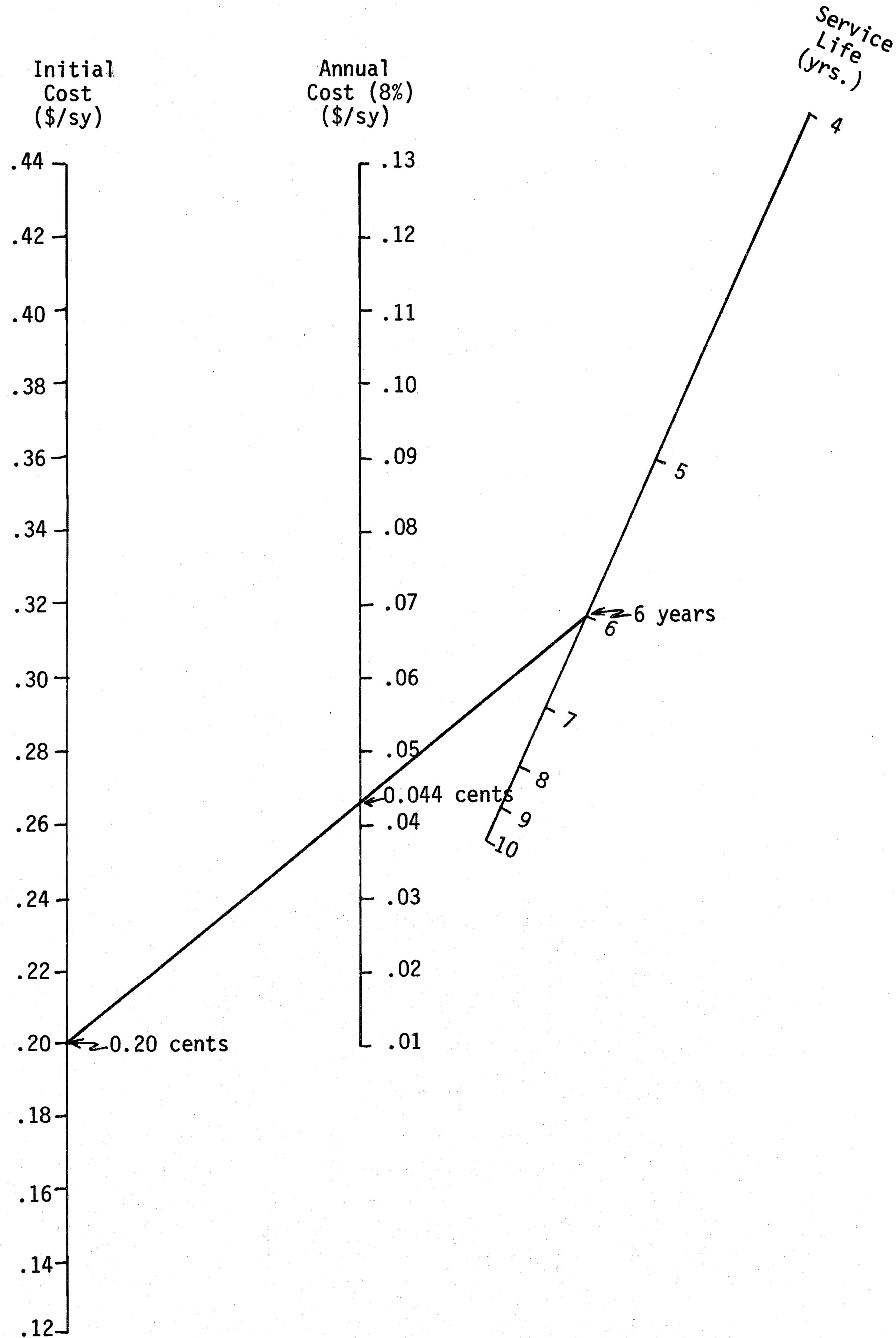


Figure 5. Annual Cost of Seal Coats

Initial in-place cost for the median gradation of each Grade and the life at which these variables have equal annual costs (4.4 cents per cubic yard) are shown below in Table 2.

Table 2. In-Place Cost and Life Giving Equal Annual Cost

Example	Aggregate Gradation	Type of Aggregate	Initial In-Place Cost, Cents	Life, years (Equal annual cost of 4.4 cents per cubic yard)
1	3	River Gravel	28.5	9.5
	4	River Gravel	20.0	6.0
	5	River Gravel	12.5	3.5
2	4	River Gravel	20.0	6.0
	4	Limestone	1.5	6.5
	4	Lightweight	27.0	9.0

These examples show that:

1. Initial cost increases considerably as the size of the aggregate increases. This cost must be offset by longer performance life of other considerations.

2. In-place of costs of real costs vary with type of aggregate even if aggregate, asphalt and construction costs are identical. This is due to variation in asphalt and aggregate required by design. This increase in cost along with possible higher aggregate costs must be offset by longer performance life or other considerations.

Gradation limits for Grades 3, 4 and 5 of Item 302 and Item 303 aggregate for normal weight surface treatments class B and lightweight respectively are shown in Table 3 for easy reference. The gradations are presented in terms of accumulative percent retained.

Table 3. Gradation Limits for
Different Grades and Item Numbers

SIEVE SIZE	GRADE					
	3		4		5	
	Item 302	Item 303	Item 302	Item 303	Item 302	Item 303
3/4 inch	0	0				
5/8 inch	0-2	0-5	0	0		
1/2 inch	20-35	30-50	0-2	0-5		0
3/8 inch	85-100	85-100	20-35	20-40	0	0-2
1/4 inch	95-100	95-100			0-5	
No. 4			95-100	95-100		60-80
No. 10	99-100	98-100	99-100	98-100	99-100	98-100

Effect of Asphalt and Aggregate Costs:

A typical Grade 4 lightweight aggregate will require approximately 0.33 gallons of asphalt cement per square yard and 1 cubic yard of aggregate will cover approximately 140 square yards of roadway surface. If asphalt cement costs 41.7 cents per gallon ($100 per ton) and lightweight aggregate costs $20 per ton, the cost of the seal coat will be 28.1 cents per square yard. The aggregate costs will be 14.3 cents per square yard and the asphalt costs 13.8 cents per square yard. From these data, it is apparent that a 10 percent increase in either the asphalt or aggregate costs will increase the total cost of the seal coat 5 percent. The sensitivity of other aggregates and gradations to changes in asphalt and aggregates costs should be evaluated on an individual basis with known asphalt and aggregate costs.

The use of emulsions in seal coat construction is gaining popularity. Examples of the use of both cationic and anionic emulsions on Interstate highways exist in several districts. Emulsions utilized with seal coat operations typically contain from 30 to 35 percent water. Thus, if seal coats constructed with emulsions are to be competitive on an equal annual cost basis with seal coats constructed with asphalt cements, a cost saving must be realized from a longer performance period, reduced construction costs, low costs of asphalt emulsion and/or a reduction in the amount of emulsion utilized over that determined by design.

Discussion

On the basis of the economic analyses presented above it is evident that Grade 5 seal coats will in many cases have a lower equal annual cost than the larger maximum size Grades 4 and 3, provided their performance periods are within a few years of each other. However, several factors, which have been outlined previously, must be recognized and are summarized below.

1. Coverstones with a relatively small maximum size are more sensitive to construction variations.
2. A more effective seal can be obtained with thick films of asphalt and hence large maximum size coverstone is desirable.
3. Pavements demonstrating flushing or bleeding are difficult to repair with seal coats. If a seal coat is to be utilized, it should have a large maximum size aggregate.
4. The potential for hydroplaning can be reduced by increasing the pavement macrotexture. A large maximum size coverstone is therefore preferred.
5. High traffic volume facilities normally utilize the larger maximum size aggregates to prevent bleeding. Bleeding may result from

orientation and densification of the coverstone under the action of the heavy traffic, construction control problems and/or by shoving of the coverstone into the underlying layer.

Unfortunately, the prediction of a performance period for the various coverstone grades on a given project is difficult. The engineer must consider the items discussed above in making this prediction as well as other factors that defy mathematical representation. Once performance periods are established, and both aggregate and asphalt costs are obtained for the various grades, an economic analysis is possible.

Economic analyses presented concerning aggregate type indicate that the natural aggregates will in general have a lower equal annual cost than synthetic aggregates, provided their performance periods are within a few years of each other. This is primarily due to the increased asphalt demand of the synthetic aggregate (Figure 1). As discussed previously, however, skid resistance is an important if not the controlling factor in selecting aggregate for surface treatments and seal coats. Performance periods from a skid resistance standpoint may be considerably greater for a synthetic aggregate than for polish susceptible limestones and river gravels. Additionally, automobile glass damage is reduced with the use of synthetic aggregates.

The above economic discussion assumes that a seal coat is the most economical solution to the pavement maintenance problem for the particular section under study. Prior to the selection of the seal coat as the pavement maintenance action, repair methods such as a thin overlay, thick overlay, open graded plant mix seal, heater-planer, heater-planer-remix, spot removal and repair and crack pouring alternatives should be investigated and an economic comparison made.

For example, assume the type of distress that exists on a roadway indicates that either a seal coat or a one-inch asphalt concrete overlay is the proper repair action. Seal coat costs for a wide variety of materials can be established on an equal annual cost basis, provided the price of the asphalt and aggregate and the pavement service life is known. At $20. per ton for asphalt concrete, the initial cost of the asphalt concrete per square yard of surface area is about $1.05. The typical inplant costs for seal coats will be 20 to 25 cents per square yard. If a seal coat has a life of six years, the equal annual cost is about 4.5 to 5.0 cents. The one-inch overlay must have a life in excess of 20 years to have an equivalent equal annual cost.

As indicated above, the key to the economic analysis is the expected performance period. This performance period will of course vary with the section under consideration. Typical longevity of different treatments is not considered in this report.

Construction and Design Guidelines

By improving material selection and specifications, and by using appropriate design procedures and sound construction practices, the engineer enhances the probability of successfully completing a project. Materials selection guidelines, a design procedure, and a method of economically evaluating alternatives are given above. Construction guidelines are offered below which will further improve the likelihood of success.

1. Traffic control should be practiced during and after construction to allow development of adequate bond between the asphalt and stone. The length of time that traffic control should be maintained is dependent upon the volume of traffic, the speed of

traffic, and the weather conditions. Normally, traffic control would be required for somewhat longer periods of time for emulsions than for asphalt cements. The use of pilot cars is advised where traffic control might be a joint effort of the Department and the contractor. Speed zoning is considered an inadequate or ineffective method of speed control.

2. Avoid construction if rainfall is likely during construction or within 24 hours after construction. If rainfall occurs during or immediately after construction, maintain traffic control until adequate adhesion has been developed between the aggregate and the asphalt. Some aggregates are much more adversely affected by rainfall than others.
3. The use of steel rollers should be avoided.
4. A seal coat design method such as that proposed in this report is recommended to improve the probability of success.
5. Aggregate spread quantities should be at a minimum. Excess aggregate on the roadway which is not removed by brooming will degrade under traffic and dislodges loosely attached material. Synthetic aggregates are very susceptible to degrading by excess aggregate.
6. The use of lightweight aggregate seal coats on very high traffic volume roads and in certain urban areas where traffic turning movements are expected should be approached with caution until sufficient information has been developed to insure the successful use of such material under these conditions.
7. For an aggregate of fixed quality, a reduction in the average particle size improves the resistance to degradation during

construction and early serivce life. Dislodgement of the aggregate is also minimized.

8. When emulsions are used, the coverstone should be applied immediately behind the distributor and the rolling operation should begin as soon as the roller will not tumble the stone.
9. Claims of degradation of lightweight aggregate during transporting and handling have not been verified. However, aggregate sampling does present a definite problem. Care must be exercised to assure the selection of representative samples, particularly for grading analysis.

Conclusions

Economical surface treatments can be placed, provided proper materials are selected, appropriate design procedures are utilized, and adequate construction procedures are followed. Information has been reviewed to assist the engineer in the vital areas.

An economic comparison of alternative aggregate types, aggregate gradations and/or asphalt types should be made for each project within service demand constraints of the project. A simplified method is presented to allow for a quick comparison of alternatives.

Note: It should be emphasized that all economic examples, costs, and cost computations are based on the assumptions stated and are subject to change. They are used for illustrative purposes only.

REFERENCES

1. "1972 Standard Specifications for Construciton of Highways, Streets and Bridges," Texas State Department of Highways and Public Transportation.

2. McLeod, N.W., "Basic Principles for the Design and Construction of Seal Coats and Surface Treatments with Cutback Asphalts and Asphalt Cements," Supplement to Volume 29, Proceedings of the Association of Asphalt Paving Technologists, 1960.

3. ____________, "A General Method of Design of Seal Coats and Surface Treatments," Proceedings of the Association of Asphalt Paving Technologists, Volume 38, 1969.

4. "Asphalt Surface Treatments and Asphalt Penetration Macadam," Manual Series No. 13, The Asphalt Institute, 1969.

5. Benson, F.J. and B.M. Gallaway, "Retention of Cover Stone by Asphalt Surface Treatments," Bulletin No. 133, Texas Engineering Experiment Station, September, 1953.

6. Epps, J.A., B.M. Gallaway, M.R. Brown, "Synthetic Aggregate Seal Coats," Report 83-2F, Texas Transportation Institute, May, 1974.