A Study of Annual Costs of Flexible and Rigid Pavements for State Highways In California

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This study provides the results for more than 600 solutions of annual costs of pavements in which the effect on the annual cost of eight major variables is clearly set forth. The variables included in the study consisted of: (1) subgrade quality for six subgrade resistance values; (2) traffic indexes for light, medium, and heavy traffic; (3) contract bid prices for all state highway pavement construction in California in 1958 and 1960 in the low range (10 percentile value), in the high range (90 percentile value), and for the arithmetic mean of all bid prices; (4) interest rates of 3 percent and 6 percent; (5) a service life of initial pavement of 13 years and 18 years was used for flexible pavements and 18 years and 26 years for rigid pavements and a service life of 13 years for the first and second asphalt concrete resurfacing was used for both flexible and rigid pavements; (6) the annual costs were computed for analysis periods of 26 years and 35 years; (7) average maintenance costs for California flexible and rigid pavements were used in the primary study and the effect of doubling and tripling the maintenance cost of flexible pavements versus no change in these costs for rigid pavements was determined on a sampling basis; and (8) a total shoulder width of 22 ft and a 2-lane pavement width of 24 ft was used in the primary study and an analysis of the effect of reduced shoulder width for 6-lane and 8-lane freeways was made on a sampling basis.

The results of the study indicated that for subgrades with resistance values (R-values) in the medium range of 25 to 60, the annual costs of flexible versus rigid pavements vary considerably, depending on the design values for the traffic index, the costs of the initial construction, and the resurfacing and maintenance costs of the particular pavement. For subgrades with R-values in the high range (above 60) the annual costs of the flexible pavements were always lower than the corresponding costs for rigid pavements. The annual cost of light-duty pavements in the majority of the solutions tended to favor the selection of flexible pavements, whereas for heavy-duty highways the majority of the solutions tended to favor the selection of rigid pavements. Resurfacing costs can have an important effect on the selection of pavement type. If a high frequency of resurfacing is expected for either the flexible or rigid type under conditions where a low frequency of resurfacing is required for the alternate type, the pavement with the longer service life will be favored on an annual cost basis. Varying the interest rates and the analysis periods influences the annual costs considerably for the two pavement types, but this effect is not as important as the effect of variations in subgrade quality, the traffic index, and the change in initial construction and resurfacing costs. The effect of varying the annual maintenance costs of the two pavement types resulted in a minor change in annual costs. Thus, the average annual maintenance costs for the two types of pavement amounted to only about 3 to 5 percent of the total annual pavement cost, and even using a

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maintenance cost for flexible pavements 3 times greater than the annual average maintenance costs resulted in no significant change in terms of the total annual costs of flexible versus rigid pavements.

This study indicates the importance of making a complete cost analysis in the selection of pavement types. The relative importance of the eight major variables in an analysis of annual costs is clearly shown in table and chart form. Although other factors, such as traffic safety, skid resistance, light-reflecting properties, esthetics, noise levels, and political decisions, should be considered in the selection of pavement types, there is evident need for adoption of a standard method for the determination of the annual costs of pavements and of giving adequate weight to annual costs in the selection of pavement types.

•A MAJOR DECISION confronting the highway engineer and administrator responsible for the planning and design of pavements for modern freeways and expressways is the selection of the pavement type, rigid or flexible, which will provide the highway user with the best possible service at the lowest cost. This selection is complicated by many factors and considerations which make it most difficult to reach a decision which is fully documented and acceptable to all interested parties.

In 1960 a report (1) prepared by the AASHO Special Committee on Project Procedures was published in which five principal factors and ten secondary factors governing the selection of pavement type were listed and discussed. The five principal factors and the ten secondary factors considered by the committee to have a major or an occasional influence in the selection of pavement type are as follows: principal factors—(1) traffic, (2) soils characteristics, (3) weather, (4) performance of similar pavements in the area, and (5) economics or cost comparison; secondary factors—(1) adjacent existing pavement, (2) stage construction, (3) depressed, surface or elevated design, (4) highway system, (5) conservation of aggregates, (6) stimulate competition, (7) construction and maintenance considerations, (8) local preference, (9) traffic safety—skid resistance, etc., and (10) availability and adaptation of local materials.

The AASHO committee did not propose a formula or a standard procedure for the selection of paving type. In the report the committee stated that "To avoid criticism, if that is possible, any decision as to paving type to be used should be firmly based. Judicious and prudent consideration and evaluation of the governing factors will result in a firm base for a decision on paving type."

The California Division of Highways and many other highway departments require an economic analysis or cost comparison as a major factor in the justification of pavement type. In 1963 the California Division of Highways adopted a new method and new cost items in making pavement cost comparisons. These new cost items have been incorporated in the study covered by this paper.

It is the contention of the authors that the principal factors proposed by the AASHO committee can be evaluated on a reasonably sound, rational and factual basis, using California pavement design formulas, and a basic formula for making pavement cost comparisons. This paper consists primarily of a broadly based investigation of the effect on pavement costs of the many factors and variables involved in the structural design of rigid and flexible pavements; the effect of the wide variations in the unit prices of various items for 155 paving projects in California for which contracts were awarded in 1960; and the effect of variations in the service life of flexible and rigid pavements, the interest rate and in the analysis period. The investigation is of the type referred to by economists as a sensitivity study.

For this study 144 pavement and shoulder design sections were developed based on the California Division of Highways rigid and flexible pavement design procedures (2). The structural design was based primarily (a) upon the resistance (R-value) of the subgrade soil, and (b) upon the Traffic Index (TI) for a 20-yr period. Six different subgrade soils ranging from R 5, very poor, to R 80, excellent, and three traffic design loads, TI = 8.5 (light-duty), TI = 10.0 (medium-duty) and TI = 11.5 (heavy-duty) were used for the study. For the portland cement concrete pavements, the standard 4-in. thickness of cement-treated base was used in this study. For the asphalt concrete pavements, the structural design was determined for three different bases: crushed stone, standard cement treated and heavy cement treated. Shoulder designs were developed for each pavement type and for each soil type and for the three traffic design loads.

It was assumed that the same subgrade construction and preparation would be required for both rigid and flexible pavement construction. In locations where subsurface water and unusual soil conditions require a special subsurface drainage design, such as the use of a permeable blanket, 1 ft in depth over the full width of the roadway, it was assumed that the same construction would be required for both rigid and flexible pavements. It is recognized, however, that unusual foundation conditions might require different subgrade treatment for the two pavement types and that this factor, which is not covered by this study, may sometimes be a controlling one in the selection of pavement type.

METHOD FOR DETERMINING ANNUAL HIGHWAY COSTS

The determination of annual highway costs has been the subject of special study and of reports by Highway Research Board committees and by individual investigators since 1920, the year the Board was established. It is significant that the Committee on Economic Theory of Highway Improvements with Dean T. R. Agg as Chairman was listed as the No. 1 committee of the Board for many years and that the Committee on Structural Design of Roads with A. T. Goldbeck as chairman was listed as the No. 2 committee. The senior author of this paper was privileged to be closely associated with Dean Agg for 25 years in making various types of economic studies. The basic principles established in those early studies played an important role in the selection of the method of analysis adopted for this study.

Dean Agg and his Committee developed procedures for determining the justification of highway improvements in terms of basic engineering economy theory. In the Committee report (3) in 1929, a method for determining the annual costs of highways was presented by Dean Agg as follows:

> The annual cost of a road... may be expressed as the total yearly expenditure that will construct, replace, and maintain in perpetuity in standard serviceable condition any existing road under existing traffic and climatic conditions.

R. H. Baldock (4) has reviewed the methods of determining annual highway costs as reported by Agg in 1929, by C. B Breed in 1934 (5) and by the Stanford Research Institute (SRI) in 1961 (6). After presenting a detailed discussion and evaluation of each method, Baldock proposed a method, patterned after the one developed by SRI, which provides for the payment of the initial construction cost and of future resurfacings on a uniform annual cost basis at a given interest rate in a definite time interval of 40 years. To this is added the average annual maintenance cost.

In June 1963, the California Division of Highways adopted a new method (7) for making economic comparisons of pavement types. The costs for each pavement type using the new method are computed in accordance with the following instructions:

1. All future pavement structural designs shall be based on 20-yr equivalent wheel load (EWL) totals.
2. An appropriate economic analysis period shall be chosen for each project based on the average life to first resurfacing of concrete pavements in the area that served under comparable conditions. In general, this will range from 20 years upward based on present experience.
3. Compound interest at the rate of 5 percent shall be used as necessary to convert all costs to present worth.
4. Initial costs shall be computed for the entire structural section including shoulders for one direction of travel and a length of one mile.
5. Estimated costs of future resurfacing shall be increased by the application of a price trend factor. Based on the California Highway Construction Cost Index, 2 percent compound interest should be used at present.

6. Engineering charges on initial construction shall be omitted, but preliminary and construction engineering charges in connection with resurfacing shall be included. This shall be expressed as a percent of the future resurfacing cost.

7. Estimates of resurfacing cost must include all supplemental work made necessary by the resurfacing. Traffic handling, temporary traffic stripes, replacing permanent traffic stripes, protection or temporary removal of guardrails, adjustments of drainage facilities, and other supplemental work should be carefully estimated.

8. The costs of traffic delay shall be estimated and added to the cost of resurfacing.

9. Maintenance costs shall be included where District records can be used to demonstrate a difference in cost between the two surface types.

10. Salvage values shall be used only as necessary to bring both estimates to the same analysis period, and should be applied to the last resurfacing only.

It should be noted that item 3 provides for a compound interest rate of 5 percent. This rate is used to convert all costs to present worth costs which are then added to the initial construction costs to obtain the total cost for the given type of pavement. Thus, instead of computing a uniform annual cost for each pavement type, the California Division of Highways computes in effect a total equivalent initial cost for each pavement type. In general, the method adopted by the California Division of Highways follows that proposed by Baldock, except that the total costs are expressed as present worth instead of a uniform annual cost.

After a careful review of all of the methods referred to above for computing the costs of pavements, the authors decided that to establish the effect of many cost variables, the annual cost method recommended by Baldock would best serve our purpose for this study. It was further decided that the three new cost items adopted by the California Division of Highways for computing resurfacing costs should be incorporated.

ANNUAL COST FORMULA

The formula recommended by Baldock for determining the annual costs to compare pavement types adopted for this study takes the following form:

$$C = CRF_n \left[A + E_1(PWF_{n_1}) + E_2(PWF_{n_2}) - (1 - \frac{y}{x})\ (E_1 \text{ or } E_2)\ PWF_{n_2} \right] + M \quad (1)$$

in which

- C = annual cost of a 2-lane mile of pavement and shoulders;
- CRF_n = capital recovery factor for an analysis period of n years and for a given interest rate;
- A = initial construction cost of pavement and shoulders, per mile;
- E_1 = first resurfacing cost, per mile;
- n_1 = service life of initial pavement surface, years;
- PWF = present worth factor for n_1 or n_2 years for a given interest rate;
- E_2 = second resurfacing cost, per mile;
- n_2 = number of years after construction to year when second resurfacing is placed;
- y = number of years from time of last resurfacing to end of analysis period;
- x = estimated life of last resurfacing, years; and
- M = average annual maintenance cost per mile.

BASIC COMPONENTS OF FORMULA

The basic components of Eq. 1 are (a) initial construction cost, (b) resurfacing costs, (c) maintenance costs, (d) interest rate, (e) analysis period, (f) service life of initial pavement surface, and (g) service life of resurfacings.

Since a major purpose for making this study was to determine the effect and relative importance of each component in Eq. 1 for computing the annual cost of each pavement type, two or more values were used for each component. The method of assigning values to the components is described in the following discussion of each of the seven components.

Initial Construction Costs—Design Sections

The initial construction cost of each pavement type was computed on the basis of the thickness and composition of the structural design sections and the unit prices for each item in the pavement cross-section which consisted of the pavement surfacing, the base, subbase and the corresponding items for the shoulders.

For this study 144 pavement and shoulder design sections were developed based on the California Division of Highways' rigid and flexible pavement design procedures published in the Division of Highways Planning Manual. The California pavement design procedures are well adapted for making cost comparisions of the type used in this study. The major factors covered by these procedures in developing the structural cross-section for each pavement type are (a) the structural quality of the basement (subgrade) soil which is measured by means of stabilometer and expansion pressure tests and is expressed as the resistance, R-value, of the soil; (b) the traffic over a 20-yr period in terms of an equivalent number of 5,000-lb wheel loads, EWL, expressed as the Traffic Index, TI; and (c) the slab value of the pavement and supporting layer, which in the design of flexible pavements is expressed in terms of the cohesiometer, C, value.

The California pavement structural design method is based on test road data and on observed performance of pavement structures. Hveem and Sherman (8) show that the thickness of flexible pavement required for a wide variety of traffic loads and materials as determined by the California design formula correlated very well (a correlation coefficient of 0.87) with the thickness requirements for the corresponding traffic loads and materials on the 2-yr AASHO Road Test in Illinois.

The structural design sections of rigid pavements investigated in the AASHO Road Test in Illinois are not directly comparable to the structural design sections of rigid pavements in California since the cement-treated base (CTB) used in California was not included in the structural design section of rigid pavements in the AASHO Road Test. However, the performance of the rigid pavements in the AASHO Road Test when compared with the California rigid pavement design for corresponding traffic loads indicated that the California rigid pavement sections are entirely adequate to carry the traffic for which the California pavements are designed.

Probably the best evidence in regard to the reliability of the California structural design procedures in assuring satisfactory performance of the pavements designed according to these procedures is the observed performance of pavements in all parts of California. For the past 12 years, tests have been conducted by the Institute of Transportation and Traffic Engineering under the direction of the senior author to measure the road roughness of both rigid and flexible pavements on state highways in all parts of California. The AASHO Road Test studies showed that road roughness measurements provided the best single indicator of pavement performance and for computing the serviceability index of a given section of pavement. The results of the road roughness measurements in California when compared with the results of similar measurements in other states and on the WASHO and AASHO road tests indicated the excellent structural quality of both the rigid and flexible pavements in California. In the judgment of the authors, the low road roughness readings and the excellent riding quality observed on California pavements provide the best evidence now available of the reliability of the California pavement design procedures to assure satisfactory pavement performance.

The structural design of rigid and flexible pavements for 4-lane freeways in California is shown in Figure 1 for typical pavement and shoulder design sections in cut and in fill. It should be noted that the design of the subbase and base requires a greater with of roadway in the fill section than in the cut section. To simplify the computations for the quantities required for various depths of pavement for cut and fill, the comparisons in this study were made on the basis of a uniform width of pavement for the traveled way of 24 ft and a uniform width for the two shoulders of 14 ft. Since the shoulder

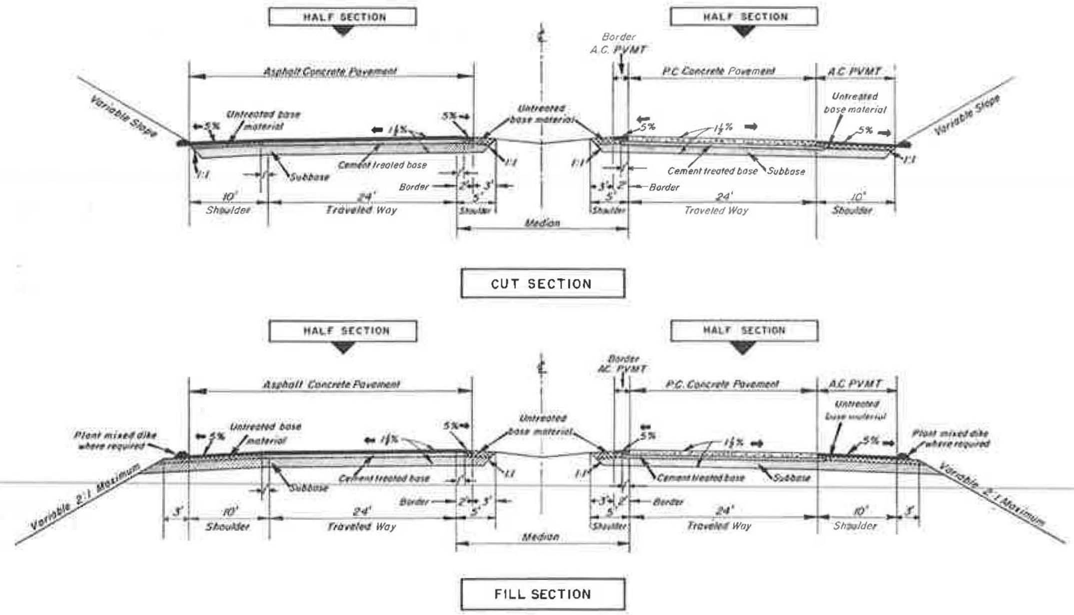

Figure 1. California Division of Highways typical pavement and shoulder design cross-section.

design for both flexible and rigid pavements in California is practically identical for corresponding traffic and soil conditions, the adoption of a uniform width of shoulder did not introduce a significant error in the quantities used or in the cost of the corresponding designs for rigid and flexible pavements.

TABLE 1

RIGID PAVEMENT STRUCTURAL DESIGN SECTIONS FOR VARIOUS SUBGRADE SOIL CONDITIONS AND FOR LIGHT-, MEDIUM-, AND HEAVY-DUTY TRAFFIC

R-Value of Subgrade Soil	Calif. Traffic Index	Rigid Pavement Design Depth (in.)			
		Portland Cement Concrete Surface	Cement-Treated Base[a]	Subbase	Total Depth
R 5	8.5	8	4-B	8	20
	10.0	9	4-A	10	23
	11.5	9	4-A	12	25
R 20	8.5	8	4-B	6	18
	10.0	9	4-A	8	21
	11.5	9	4-A	10	23
R 35	8.5	8	4-B	6	18
	10.0	9	4-A	6	19
	11.5	9	4-A	8	21
R 50	8.5	8	4-B	6	18
	10.0	9	4-A	6	19
	11.5	9	4-A	6	19
R 65	8.5	8	4-B	—	12
	10.0	9	4-A	—	13
	11.5	9	4-A	—	13
R 80	8.5	8	4-B	—	12
	10.0	9	4-A	—	13
	11.5	9	4-A	—	13

[a]The two types of cement treated base used in this study consist of: (1) Type A with 3½ to 6% portland cement by weight of the dry aggregate, and (2) Type B with 2½ to 4½% portland cement by weight of the dry aggregate.

The rigid pavement structural design sections for six subgrade soil types ranging from a very poor R 5 soil to an excellent R 80 soil and for three traffic design loads, TI = 8.5 (light-duty), TI = 10.0 (medium-duty) and TI = 11.5 (heavy-duty) are given in Table 1. For light-duty traffic, a uniform portland cement concrete pavement slab thickness of 8 in. is used in California. For medium-duty and heavy-duty traffic, this thickness is increased to 9 in. It should be noted that a 4-in. cement-treated base (CTB) is used in all of the rigid pavement design sections and that a varying depth of subbase is used, based upon the R-value of the subgrade soil and the Traffic Index.

The flexible pavement structural design sections given in Table 2 were developed for the same R-values for the subgrade soil and the same TI values for traffic used in the design of the rigid pavement sections, except that three types of base courses, crushed stone, standard CTB and heavy CTB, were used in developing

TABLE 2

FLEXIBLE PAVEMENT STRUCTURAL DESIGN SECTIONS FOR VARIOUS SUBGRADE SOIL CONDITIONS AND FOR LIGHT-, MEDIUM-, AND HEAVY-DUTY TRAFFIC

R-Value of Subgrade Soil	Calif. Traffic Index	Flexible Pavement Design Depth, in Inches											
		With Crushed Stone Base				With Standard CTB Base				With Heavy CTB Base			
		Asphalt Concrete Surface	Crushed Stone Base	Subbase	Total Depth	Asphalt Concrete Surface	CTB Base[a]	Subbase	Total Depth	Asphalt Concrete Surface	CTB Base[a]	Subbase	Total Depth
R 5	8.5	3½	8	15	26½	3	8-A	10	21	3	10-A	7	20
	10.0	4	10	18	32	4	10-A	11	25	4	10-A	10	24
	11.5	6	10	20	36	6	10-A	13	29	6	10-A	12	28
R 20	8.5	3½	8	11	22½	3	8-A	5	16	3	8-A	5	16
	10.0	4	10	12	26	4	10-A	5	19	4	10-A	5	19
	11.5	6	10	13	29	6	10-A	6	22	6	10-A	6	22
R 35	8.5	3½	8	6	17½	3	8-A	—	11	3	8-A	—	11
	10.0	4	10	6	20	4	10-A	—	14	4	5-A	5	14
	11.5	6	10	7	23	6	10-A	—	16	6	5-A	5	16
R 50	8.5	3½	9	—	12½	3	8-B	—	11	3	8-B	—	11
	10.0	4	10	—	14	4	10-A	—	14	4	10-A	—	14
	11.5	6	10	—	16	6	10-A	—	16	6	10-A	—	16
R 65	8.5	3½	8	—	11½	3	8 Cr. St.	—	11	3	8 Cr. St.	—	11
	10.0	4	10	—	14	4	10 Cr. St.	—	14	4	10 Cr. St.	—	14
	11.5	6	10	—	16	6	10 Cr. St.	—	16	6	10 Cr. St.	—	16
R 80	8.5	3½	8	—	11½	3	8 Cr. St.	—	11	3	8 Cr. St.	—	11
	10.0	4	10	—	14	4	10 Cr. St.	—	14	4	10 Cr. St.	—	14
	11.5	6	10	—	16	6	10 Cr. St.	—	16	6	10 Cr. St.	—	16

[a]The two types of cement/treated base used in this study consist of: (1) Type A with 3½ to 6 percent portland cement by weight of the dry aggregate. (2) Type B with 2½ to 4½ percent portland cement by weight of the dry aggregate. For subgrade soils with R-values of 65 and 80, a crushed stone base is used instead of a cement-treated base.

TABLE 3

SHOULDERS STRUCTURAL DESIGN SECTIONS FOR RIGID AND FLEXIBLE PAVEMENTS DESIGNED FOR VARIOUS SOIL CONDITIONS AND FOR LIGHT-, MEDIUM-, AND HEAVY-DUTY TRAFFIC

R-Value of Subgrade Soil	Calif. Traffic Index	Shoulder Design Depth, in Inches[a]										
		Minimum Depths Based on Design Formula			Depths Adopted for Rigid Pavements with Cement-Treated Base				Depths Adopted for Flexible Pavements with Standard CTB Base			
		Asphalt Concrete Surface	Base and Subbase	Total Depth	Asphalt Concrete Surface	Base—Crushed Stone	Subbase	Total Depth	Asphalt Concrete Surface	Base—Crushed Stone	Subbase	Total Depth
R 5	8.5	2	15	17	3-2	4	13	20	3-2	4	14	21
	10.0	3	18	20	4-2	4	15	23	4-2	4	17	25
	11.5	3	20	23	4-2	4	17	25	4-2	4	21	29
R 20	8.5	2	12	14	3-2	4	11	18	3-2	4	9	16
	10.0	3	13	16	4-2	4	13	21	4-2	4	11	19
	11.5	3	16	19	4-2	4	15	23	4-2	4	14	22
R 35	8.5	2	9	11	3-2	4	11	18	3-2	4	4	11
	10.0	3	10	13	4-2	4	11	19	4-2	4	6	14
	11.5	3	12	15	4-2	4	13	21	4-2	4	8	16
R 50	8.5	2	6	8	3-2	4	11	18	3-2	4	4	11
	10.0	3	7	10	4-2	4	11	19	4-2	4	6	14
	11.5	3	8	11	4-2	4	11	19	4-2	4	8	16
R 65	8.5	2	3	5	3-2	4	5	12	3-2	4	4	11
	10.0	3	3	6	4-2	4	5	13	4-2	4	6	14
	11.5	3	5	8	4-2	4	5	13	4-2	4	8	16
R 80	8.5	2	—	2	3-2	4	5	12	3-2	4	4	11
	10.0	3	—	3	4-2	4	5	13	4-2	4	6	14
	11.5	3	—	3	4-2	4	5	13	4-2	4	8	16

[a]The shoulder design adopted for both the rigid and flexible pavement types provides for a uniform depth of pavement and shoulder cross-section.

the flexible pavement sections instead of only one type of base used for the rigid pavement sections. It should be noted that for light-duty traffic a 3½-in. asphalt concrete pavement thickness was used and for heavy-duty traffic a 6-in. thickness was used. The maximum total depth for the flexible pavement design was 36 in. as compared with a 25-in. depth for the corresponding rigid pavement design section. The minimum total depth for the flexible pavement design was 11 in. as compared with a minimum depth of 12 in. for the rigid pavement design. The above minimum depths of pavement apply only to well-drained soils with high R-values where a subbase is not required for either flexible or rigid pavements.

The shoulder design sections for both the rigid and flexible pavement cross-sections are given in Table 3. The shoulder design in California is based on a traffic design load of 1 percent of the EWL but with a TI of not less than 4.5 or more than 7.5. In

TABLE 4

UNIT CONTRACT PRICES FOR THE CONSTRUCTION OF PORTLAND CEMENT CONCRETE PAVEMENTS ON 37 CALIFORNIA STATE HIGHWAY PROJECTS IN 1958 AND ON 44 PROJECTS IN 1960

Pavement Item	Contract Price Rating[a]	Unit Price ($ per sq yd) 1958	1960
Concrete paving, including tie bolts:			
8-in. thickness	Low	3.00	2.80
	High	4.70	3.70
	Average	3.52	3.20
9-in. thickness	Low	3.40	3.30
	High	4.80	4.50
	Average	3.97	3.83
Base course, including curing seal:			
Cement-treated (Type A), 4-in. thick.	Low	0.50	0.65
	High	1.00	0.90
	Average	0.77	0.79
Cement-treated (Type B), 4-in. thick.	Low	-	0.45
	High	-	0.75
	Average	-	0.60
Subbase:			
Imported borrow, per inch of thickness	Low	0.03	0.03
	High	0.12	0.12
	Average	0.07	0.06

[a]The contract price rating adopted for this study was established on the following basis:
Low—represents the 10 percentile value.
High—represents the 90 percentile value.
Average—represents the arithmetical mean.

TABLE 5

UNIT CONTRACT PRICES FOR THE CONSTRUCTION OF ASPHALT CONCRETE PAVEMENTS ON 63 STATE HIGHWAY PROJECTS IN CALIFORNIA IN 1958 AND ON 111 PROJECTS IN 1960

Pavement Item	Contract Price Rating[a]	Unit Price ($ per sq yd) 1958	1960
Asphalt concrete surface:			
1-in. thickness	Low	-	0.33
	High	-	0.49
	Average	-	0.40
2-in. thickness	Low	0.60	0.61
	High	0.96	0.89
	Average	0.72	0.73
3-in. thickness	Low	0.75	0.78
	High	1.12	1.23
	Average	0.92	1.05
4-in. thickness	Low	1.10	1.15
	High	1.55	1.69
	Average	1.25	1.34
6-in. thickness	Low	-	1.71
	High	-	2.49
	Average	-	1.98
Prime coat	Low	0.03	0.03
	High	0.05	0.09
	Average	0.04	0.06
Base course:			
Cement-treated—Type A per inch of thickness	Low	0.16	0.16
	High	0.23	0.24
	Average	0.20	0.19
Cement-treated—Type B per inch of thickness	Low	0.13	0.12
	High	0.22	0.20
	Average	0.17	0.17
Crushed stone base per inch of thickness	Low	0.06	0.07
	High	0.13	0.14
	Average	0.09	0.10
Subbase:			
Imported borrow, per inch of thickness	Low	0.03	0.03
	High	0.11	0.12
	Average	0.06	0.06

[a]The contract price rating adopted for this study was established on the following basis: low—represents the 10 percentile value, high—represents the 90 percentile value, and average—represents the arithmetical mean.

Table 3, the minimum depths of shoulder based on the above design criteria are given. The shoulder design adopted for both the rigid and flexible pavement types, however, provided for a uniform depth of pavement and shoulder which in all cases was greater than the minimum depth based on the traffic requirements. The use of a uniform depth of pavement and shoulder instead of a trench section is a design procedure widely used today in California and in many other states. For poor subgrade soil types, it increased the required depth of shoulders for flexible pavements by a greater amount than the depth of shoulders required for rigid pavements. For subgrade soils with R-values of 35 and 50, the required depths of shoulder for flexible pavements in this study were slightly lower than for rigid pavements. For R-values of 65 and 80, the shoulder depths for flexible pavements were the same or slightly higher than for rigid pavements.

The initial construction costs for the pavements and shoulders were computed using cost data obtained from the 1958 and 1960 annual reports of the "Construction Costs of Portland Cement Concrete Pavements and of Asphalt Concrete Pavements on Highways in California" prepared by the Pacific Coast Division of The Asphalt Institute (9). The accuracy of the unit cost data in these reports was verified by the authors and by the design engineers of the California Division of Highways by comparing the unit costs in these reports with the original records of contract bid prices and with the cost data in the California Division of Highways Contract Item Data Report for 1960 (10).

The unit contract prices for the construction of portland cement concrete pavements on 37 California state highway projects in 1958 and on 44 projects in 1960 are given in Table 4 and the corresponding costs for asphalt concrete pavements on 63 projects in 1958 and for 111 projects in 1960 are given in Table 5. For this study the unit costs for 155 paving projects for which contracts were awarded in California in 1960 were used as given in Tables 4 and 5. The unit prices for each pavement item for which

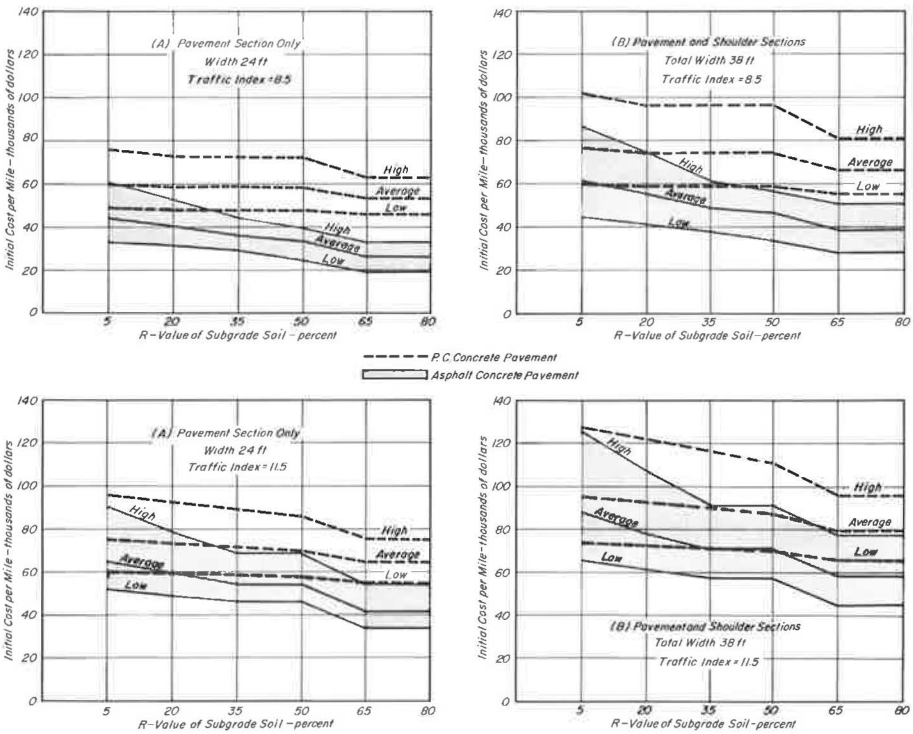

Figure 2. Initial construction costs per mile for (a) 2-lane concrete and asphalt pavements and (b) pavements and shoulders, designed for six subgrade soil types, for light-duty traffic (TI = 8.5) and heavy-duty traffic (TI = 11.5).

TABLE 6

INITIAL CONSTRUCTION COSTS PER MILE FOR 2-LANE PORTLAND CEMENT CONCRETE PAVEMENT AND SHOULDERS[a]

Design Section				Contract Price Rating	Initial Construction Costs per Mile			
No.	R-Value of Subgrade Soil	Traffic Index	Total Pvmt. Depth (in.)		Cost of Pavement per Mile ($)	Cost of Shoulders per Mile ($)	Ratio Pvmt. vs Shoulder Costs per Mile	Total Cost, Pavement and Shoulders per Mile ($)
1	R 5	8.5	20	Low	49,140	11,250	4.4	60,390
				High	76,170	26,120	2.9	102,290
				Average	60,260	17,000	3.5	77,260
2		10.0	23	Low	59,840	12,400	4.8	72,240
				High	92,930	29,490	3.2	122,420
				Average	73,500	19,300	3.8	92,800
3		11.5	25	Low	60,680	12,890	4.9	73,570
				High	96,310	31,460	3.1	127,770
				Average	75,190	20,290	3.7	95,480
7	R 35	8.5	18	Low	48,290	10,760	4.6	59,050
				High	72,800	24,150	3.0	96,950
				Average	58,570	16,020	3.7	74,590
8		10.0	19	Low	58,150	11,420	5.1	69,570
				High	86,170	25,540	3.5	111,710
				Average	70,120	17,330	4.0	87,450
9		11.5	21	Low	59,000	11,910	5.0	70,910
				High	89,550	27,510	3.3	117,060
				Average	71,810	18,320	3.9	90,130
10	R 50	8.5	18	Low	48,290	10,760	4.5	59,050
				High	72,800	24,150	3.0	96,950
				Average	58,570	16,020	3.7	74,590
11		10.0	19	Low	58,150	11,420	5.1	69,570
				High	86,170	25,540	3.4	111,710
				Average	70,120	17,330	3.5	87,450
12		11.5	19	Low	58,150	11,420	5.1	69,570
				High	86,170	25,540	3.4	111,710
				Average	70,120	17,330	4.0	87,450
13	R 65	8.5	12	Low	45,760	9,280	4.9	55,040
				High	62,660	18,230	3.4	80,890
				Average	53,500	13,060	4.1	66,560
14		10.0	13	Low	55,620	9,940	5.6	65,560
				High	76,030	19,630	3.9	95,660
				Average	65,050	14,370	4.5	79,420
15		11.5	13	Low	55,620	9,940	5.6	65,560
				High	76,030	19,630	3.9	95,660
				Average	65,050	14,370	4.5	79,420

[a]Based on the contract prices for 44 state highway paving projects in 1960.

TABLE 7

INITIAL CONSTRUCTION COSTS PER MILE FOR 2-LANE ASPHALT CONCRETE PAVEMENT AND SHOULDERS WITH CRUSHED STONE BASE[a]

Design Section				Contract Price Rating	Initial Construction Costs per Mile			
No.	R-Value of Subgrade Soil	Traffic Index	Total Pvmt. Depth (in.)		Cost of Pavement per Mile ($)	Cost of Shoulders per Mile ($)	Cost of Pvmt. vs Shoulder Costs per Mile	Total Cost, Pavement and Shoulders per Mile ($)
1	R 5	8.5	26½	Low	27,680	12,890	2.2	40,770
				High	61,670	32,520	1.9	94,190
				Average	40,830	20,200	2.0	61,030
2		10.0	32	Low	33,650	14,620	2.3	48,270
				High	73,920	38,360	1.9	112,280
				Average	48,150	23,740	2.0	71,890
3		11.5	36	Low	42,380	15,610	2.7	57,990
				High	88,560	42,300	2.1	130,860
				Average	58,850	25,710	2.3	84,560
7	R 35	8.5	17½	Low	24,080	10,680	2.3	34,760
				High	46,460	23,650	2.0	70,110
				Average	33,230	15,770	2.1	49,000
8		10.0	20	Low	28,580	11,660	2.5	40,240
				High	53,640	26,530	2.0	80,170
				Average	38,020	17,820	2.1	55,840
9		11.5	23	Low	36,890	11,580	3.2	48,470
				High	66,600	29,490	2.3	96,090
				Average	47,870	19,300	2.5	67,170
10	R 50	8.5	12½	Low	22,530	9,450	2.4	31,980
				High	38,300	18,730	2.0	57,030
				Average	29,570	13,310	2.2	42,880
11		10.0	14	Low	26,050	10,180	2.6	36,230
				High	43,510	20,620	2.1	64,130
				Average	32,950	14,870	2.2	47,820
12		11.5	16	Low	33,930	10,680	3.2	44,610
				High	54,770	22,590	2.4	77,360
				Average	41,960	15,850	2.6	57,810
13	R 65	8.5	11½	Low	21,540	9,200	2.3	30,740
				High	36,330	17,740	2.1	54,070
				Average	28,160	12,810	2.2	40,970
14		10.0	14	Low	26,050	10,180	2.6	36,230
				High	43,510	20,620	2.1	64,130
				Average	32,950	14,870	2.2	47,820
15		11.5	16	Low	33,930	10,680	3.2	44,610
				High	54,770	22,590	2.4	77,360
				Average	41,960	15,850	2.6	57,810

[a]Based on the contract prices for 111 state highway paving projects in 1960.

TABLE 8

INITIAL CONSTRUCTION COSTS PER MILE FOR 2-LANE ASPHALT CONCRETE PAVEMENT AND SHOULDERS WITH STANDARD CEMENT TREATED BASE[a]

Design Section				Contract Price Rating	Initial Construction Costs per Mile			
No.	R-Value of Subgrade Soil	Traffic Index	Total Pvmt. Depth (in.)		Cost of Pavement per Mile ($)	Cost of Shoulders per Mile ($)	Ratio Pvmt. vs Shoulder Costs per Mile	Total Cost, Pavement and Shoulders per Mile ($)
1	R 5	8.5	21	Low	33,230	11,500	2.8	44,730
				High	61,250	26,280	2.3	87,530
				Average	44,630	17,490	2.6	62,120
2		10.0	25	Low	43,370	12,890	3.4	56,260
				High	76,170	32,610	2.3	108,780
				Average	54,910	20,860	2.6	75,770
3		11.5	29	Low	52,100	13,880	3.8	65,980
				High	90,820	35,400	2.6	126,220
				Average	65,610	22,260	3.0	87,870
7	R 35	8.5	11	Low	29,000	9,030	3.2	38,030
				High	44,350	17,250	2.6	61,600
				Average	36,190	12,520	2.9	48,700
8		10.0	14	Low	38,720	10,180	3.8	48,900
				High	57,590	20,620	2.8	78,210
				Average	45,620	14,870	3.1	60,490
9		11.5	16	Low	46,600	10,680	4.4	57,280
				High	68,850	22,590	3.1	91,440
				Average	54,630	15,850	3.5	70,480
10	R 50	8.5	11	Low	24,500	9,030	2.7	33,530
				High	30,860	17,250	2.3	57,100
				Average	33,930	12,520	2.7	46,500
11		10.0	14	Low	38,720	10,180	3.8	48,900
				High	57,590	20,620	2.8	78,210
				Average	45,620	14,870	3.1	60,490
12		11.5	16	Low	46,600	10,680	4.4	57,280
				High	68,850	22,590	3.0	91,440
				Average	54,630	15,850	3.4	70,480
13	R 65[b]	8.5	11	Low	18,870[b]	9,030	2.1	27,900[b]
				High	33,090	17,250	1.9	50,340
				Average	26,050	12,570	2.1	38,620
14		10.0	14	Low	26,050[b]	10,180	2.6	36,230[b]
				High	43,510	20,620	2.1	64,130
				Average	32,950	14,870	2.2	47,820
15		11.5	16	Low	33,930[b]	10,680	3.2	44,610[b]
				High	54,770	22,590	2.4	77,360
				Average	41,960	15,850	2.6	57,810

[a]Based on the contract prices for 111 state highway paving projects in 1960.
[b]For subgrade soils with R-values of 65, a crushed stone base is used instead of a cement-treated base. Hence, the cost of the pavement portion of the roadway for the R 65 soils was computed using the unit prices for crushed stone base instead of cement-treated base construction.

TABLE 9

INITIAL CONSTRUCTION COSTS PER MILE FOR 2-LANE ASPHALT CONCRETE PAVEMENT AND SHOULDERS WITH HEAVY CEMENT-TREATED BASE[a]

Design Section				Contract Price Rating	Initial Construction Costs per Mile			
No.	R-Value of Subgrade Soil	Traffic Index	Total Pvmt. Depth (in.)		Cost of Pavement per Mile ($)	Cost of Shoulders per Mile ($)	Ratio Pvmt. vs Shoulder Costs per Mile	Total Cost, Pavement and Shoulders per Mile ($)
1	R 5	8.5	20	Low	36,470	11,250	3.2	47,720
				High	62,940	26,120	2.4	89,060
				Average	47,450	17,000	2.8	64,450
2		10.0	24	Low	42,940	12,650	3.4	55,590
				High	74,480	30,470	2.4	104,950
				Average	54,070	19,790	2.7	73,860
3		11.5	28	Low	51,670	13,640	3.8	65,310
				High	80,130	34,410	2.6	123,540
				Average	64,770	21,770	3.0	86,540
7	R 35	8.5	11	Low	29,000	9,030	3.2	38,030
				High	44,350	17,250	2.6	61,600
				Average	36,190	12,570	2.9	40,760
8		10.0	14	Low	35,900	10,180	3.5	46,080
				High	54,770	20,620	2.7	75,390
				Average	44,210	14,870	3.0	59,080
9		11.5	16	Low	43,790	10,680	4.1	54,470
				High	66,040	22,590	2.9	88,630
				Average	53,220	15,850	3.4	69,030
10	R 50	8.5	11	Low	24,500	9,030	2.7	33,530
				High	39,850	17,250	2.3	57,100
				Average	33,930	12,570	2.7	46,500
11		10.0	14	Low	38,720	10,180	3.8	48,900
				High	57,590	20,620	2.8	78,210
				Average	45,620	14,870	3.1	60,490
12		11.5	16	Low	46,600	10,680	4.4	57,280
				High	68,850	22,590	3.0	91,440
				Average	54,630	15,850	3.4	70,480
13	R 65[b]	8.5	11	Low	18,870[b]	9,030	2.1	27,900[b]
				High	33,090	17,250	1.9	50,340
				Average	26,050	12,570	2.1	38,620
14		10.0	14	Low	26,050[b]	10,180	2.6	36,230[b]
				High	43,510	20,620	2.1	64,130
				Average	32,950	14,870	2.2	47,820
15		11.5	16	Low	33,930[b]	10,680	3.2	44,610[b]
				High	54,770	22,590	2.4	77,360
				Average	41,960	15,850	2.6	57,810

[a]Based on the contract prices for 111 state highway paving projects in 1960.
[b]For subgrade soils with R-values of 65, a crushed stone base is used instead of a cement-treated base. Hence, the cost of the pavement portion of the roadway for the R 65 soils was computed using the unit prices for crushed stone base instead of cement-treated base construction.

bids were submitted, such as for the portland cement concrete and asphalt concrete surfaces, for the various types of base courses, and for the subbases were reduced to a common unit adopted for this study: the unit price in dollars per sq yd per inch of thickness or for a given design thickness (i.e., for an 8-in. portland cement concrete slab or a 4-in. CTB). To indicate the wide range in the contract prices for projects in all parts of California, a price rating method was adopted in which low represents the 10 percentile value and high the 90 percentile value for all contract prices of similar items for the 155 paving projects. Average represents the arithmetical mean for all prices of similar items.

The unit cost data given in Tables 4 and 5 indicate a surprising uniformity in the contract prices for the same pavement items in 1958 and 1960. It is significant that certain recent improvements in the construction of portland cement concrete pavements, such as the use of slip-form pavers and of paving over 2-lane widths instead of 1-lane widths, appear to have brought about the decrease in unit prices for 1960 given in Table 4. The data in Table 5 indicate a slight increase in the unit prices for asphalt concrete pavements over the 2-yr period from 1958 to 1960.

The initial construction costs of the rigid and flexible pavements, of the shoulders, and of the total roadway section were computed in terms of a 2-lane roadway one mile in length for one direction of travel. The computed costs are shown in Figure 2 and in Tables 6, 7, 8, and 9. The costs for the six subgrade soils shown in Figure 2, starting with the very high costs for pavements designed for the very poor R 5 soil to the low costs for pavements designed for the excellent R 80 soils, show a uniform pattern and trend in costs which may be attributed to the type of subgrade soil. Since the trend in costs is clearly indicated in Figure 2, the values for the initial construction costs are shown only for the R 5, R 35 and R 65 soils in Tables 6 to 9, thereby eliminating the duplication of costs for certain soil types and reducing the size and complexity of the tables.

It should be noted in Figure 2 and in Tables 6 to 9 that by including the cost of shoulders in the comparison of initial construction costs of rigid and flexible pavements, a variable cost factor is introduced which reduces the cost differential between rigid and flexible pavements for many of the design sections, especially for the sections with the greater pavement depth. For rigid pavements, the ratio of pavement to shoulder costs varies from 3.0 to 5.6, whereas for flexible pavements this ratio varies from 2.0 to 4.4. A major reason for the higher costs of shoulders for flexible pavements, where this occurs, is the greater depth of pavement required for these sections which in turn require a greater shoulder depth in accordance with the uniform pavement and shoulder depth design procedure adopted for this study.

Table 6 gives the initial costs for the portland cement concrete pavement sections, the shoulder sections, and the combined concrete pavement and shoulder sections. In California only one type of base, the 4-in. CTB, is normally used in the construction of concrete pavements, and therefore all of the initial costs for the portland cement concrete pavement sections used in this study are given in one table. However, in computing the construction costs of asphalt concrete pavements, three types of bases—crushed stone, standard CTB, and heavy CTB—were used, and accordingly the initial costs for the asphalt concrete pavement and shoulder sections with each of these three bases are given in Tables 7, 8 and 9.

A significant feature of the initial costs given in Tables 6 to 9 is the wide range in the initial costs for both the rigid and flexible pavement construction required to satisfy the structural design requirements for the various soil types and traffic loads. For many of the sections, especially for the sections with the greatest pavement depths designed for poor subgrade soil conditions, the spread in the initial costs from high to low based on the contract bid prices in 1960 was greater than the spread in costs due to the variations in pavement design sections. The wide range in the construction costs per 2-lane mile for pavement and shoulders based on 1960 prices is indicated in the following comparison of the costs for the maximum depth of pavement required for heavy-duty traffic and a very poor R 5 subgrade soil and the minimum depth of pavement required for light-duty traffic and an excellent R 80 subgrade soil:

Pavement Items and Depth	Soil	Traffic	Pavement Depth (in.)	Cost per Mile ($)	
				High	Low
Portland cement concrete (9 in.) with cement-treated base (CTB) (4 in.)	R 5	TI = 11.5	25	$127,800	$73,600
Asphalt concrete (6 in.) with crushed stone base (10 in.), standard CTB	R 5	TI = 11.5	36	130,900	58,000
(10 in.), heavy CTB	R 5	TI = 11.5	29	126,200	66,000
(10 in.)	R 5	TI = 11.5	28	123,500	65,300
Portland cement concrete (8 in.) with CTB (4 in.)	R 80	TI = 8.5	12	$ 88,900	$ 55,000
Asphalt concrete (3 in.) with crushed stone base (8 in.)	R 80	TI = 8.5	11	50,300	27,900

These data show that the construction costs of rigid and flexible pavements designed for heavy-duty traffic and for poor soil conditions are all within the same price bracket but that the costs of the rigid pavement designed for light-duty traffic and for excellent soil conditions are almost double the costs of flexible pavements designed for these same conditions.

It is interesting to note in the foregoing comparision of initial costs for asphalt concrete pavements with three types of base construction and in the complete listing of these costs given in Tables 7, 8, and 9, that there is a marked difference in the initial cost of flexible pavements depending on the type of base course used. When only the pavement sections are considered, the pavements with the crushed stone base were generally found to have the lowest initial costs, but when the costs were computed for the full width of roadway including the shoulders, the standard CTB yielded the lowest cost, except for the sections designed for very poor soils and for heavy-duty traffic where the heavy CTB construction was lowest. These data clearly indicate that cost comparisions should be made for each type of base construction since the data show that under certain specific traffic and soil conditions each type of base may provide a definite cost advantage which can and should be evaluated.

It is readily apparent from an examination of the initial construction cost data given in Figure 2 and in Tables 6 to 9, that with pavement depths ranging from 11 to 36 in., there should be a corresponding spread in the initial construction costs. The reason for the wide spread in actual construction costs for the same pavement design section, however, is not so apparent and is rather difficult to explain. Indeed, there are many factors which influence the contract price for the various items in the construction of pavements in a state as large as California with such a wide range in climate, availability, and quality of paving materials, and in many other factors which influence pavement costs. The unit prices for various paving items given in Tables 4 and 5 indicate a much wider spread in the cost of aggregates used in base and subbase construction than in the cost of asphalt concrete or portland cement concrete pavement surfacing. The size and location of the paving projects, the access to paving plants and/or the cost of moving paving plants from one job to another, the competition in bidding on various paving projects, the supply of labor and materials, unbalanced bidding, traffic conflicts, controls and detour requirements, and the climatic or weather conditions during construction are factors which contributed to the wide variations in the unit bid prices submitted by various contractors for the various items on paving projects for which contracts were awarded in California in 1960.

It should be evident on the basis of the foregoing discussion that pavement cost comparisons should be made on a project-by-project basis using the structural design, traffic, and cost data which apply to the particular area and project under consideration instead of using statewide cost data of the type used in this study. The use of statewide cost data in this study resulted in the wide spread in the initial costs for both rigid and flexible pavements shown in Figure 2.

Resurfacing Costs

The resurfacing thickness requirements and costs for both the rigid and flexible pavement types were assumed to be independent of the structural design sections for each pavement type. Although a greater thickness was used for the first resurfacing of the portland cement concrete pavements than for the asphalt concrete pavements, the same resurfacing thickness was used for each pavement type for each of the 18 design sections.

The California Division of Highways has been engaged in extensive resurfacing programs for many years. Asphalt concrete overlays of various thicknesses have been used to resurface both rigid and flexible pavements. In 1960 about 70 percent of the total mileage or resurfacing of flexible pavements consisted of an asphalt concrete overlay with a uniform thickness of 1 in. For the remaining mileage the thickness was increased to 1 ½ in. and 2 in. For rigid pavements an asphalt concrete overlay with an average thickness of 3 in. was used. The 3-in. thickness of asphalt concrete overlay has been widely used in many states for resurfacing portland cement concrete pavements and was adopted as the thickness for resurfacing the rigid pavements in this study. For flexible pavements an average thickness of 1 ½ in. was used for resurfacing the traveled way portion of the roadway.

For resurfacing the shoulders a tapered section was adopted for both the rigid and flexible pavement sections. For the rigid pavements, a thickness of 3 in. at the edge of the traveled way was tapered to 1 in. at the outer edge of the shoulder for the first resurfacing. Where a second resurfacing was used on rigid pavements, the thickness

TABLE 10

RESURFACING COSTS PER MILE FOR 2-LANE WIDTH OF RIGID PAVEMENT AND FOR SHOULDERS[a]

Traffic Index	1960 Contracts: Price Rating	1960 Contracts: Costs per Mile ($)	Costs at End of 18th Yr (2% price-trend factor = 1.4282) ($)	Costs for Engg. (10%) and Suppl. Work (6%) ($)	Traffic Delay and Accident Costs ($)	Total Resur. Costs at End of 18th Yr ($)	Present Worth Resur. Costs: Int. at 3% ($)	Present Worth Resur. Costs: Int. at 6% ($)
(a) Pavement Resurfacing Costs per Mile								
8.5	Low	10,980	15,680	2,510	20	18,210	10,700	6,380
	High	17,320	24,740	8,960	20	28,720	16,870	10,060
	Avg.	14,780	21,110	3,380	20	24,510	14,400	8,590
10.0	Low	10,980	15,680	2,510	100	18,290	10,740	6,410
	High	17,320	24,740	8,960	100	28,800	16,910	10,090
	Avg.	14,780	21,110	3,380	100	24,590	14,440	8,610
11.5	Low	10,980	15,680	2,510	300	18,490	10,860	6,480
	High	17,320	24,740	8,960	300	29,000	17,030	10,160
	Avg.	14,780	21,110	3,380	300	24,790	14,670	8,680
(b) Shoulder Resurfacing Costs per Mile								
8.5	Low	5,010	7,160	1,150	20	8,330	4,890	2,920
	High	7,310	10,440	1,670	20	12,130	7,130	4,250
	Avg.	6,000	8,570	1,370	20	9,960	5,850	3,490
10.0	Low	5,010	7,160	1,150	80	8,390	4,930	2,940
	High	7,310	10,440	1,670	80	12,190	7,160	4,270
	Avg.	6,000	8,570	1,370	80	10,020	5,890	3,510
11.5	Low	5,010	7,160	1,150	240	8,550	5,020	3,000
	High	7,310	10,440	1,670	240	12,350	7,250	4,330
	Avg.	6,000	8,570	1,370	240	10,180	5,980	3,570

[a] Service life of pavement, 18 yr; life of asphalt concrete resurfacing, 13 yr; analysis period, 26 yr; thickness of asphalt concrete resurfacing for pavement, 3 in., and for shoulders, 2 in.

TABLE 11

RESURFACING COSTS PER MILE FOR 2-LANE WIDTH OF RIGID PAVEMENT AND FOR SHOULDERS[a]

Traffic Index	1960 Contracts: Price Rating	1960 Contracts: Costs per Mile ($)	Costs at End of 26th Yr (2% price-trend factor = 1.6734) ($)	Costs for Engg. (10%) and Suppl. Work (6%) ($)	Traffic Delay and Accident Costs ($)	Total Resur. Costs at End of 26th Yr ($)	Present Worth Resur. Costs: Int. at 3% ($)	Present Worth Resur. Costs: Int. at 6% ($)
(a) Pavement Resurfacing Costs per Mile								
8.5	Low	10,980	17,970	2,880	20	20,870	9,680	4,590
	High	17,320	28,350	4,540	20	32,910	15,260	7,230
	Avg.	14,780	24,190	3,870	20	28,080	13,020	6,170
10.0	Low	10,980	17,970	2,880	100	20,950	9,710	4,600
	High	17,320	28,350	4,540	100	32,990	15,300	7,250
	Avg.	14,780	24,190	3,870	100	28,160	13,060	6,190
11.5	Low	10,980	17,970	2,880	300	21,150	9,810	4,650
	High	17,320	28,350	4,540	300	33,190	15,390	7,300
	Avg.	14,780	24,190	3,870	300	28,360	13,150	6,230
(b) Shoulder Resurfacing Costs per Mile								
8.5	Low	5,010	8,380	1,340	20	9,740	4,520	2,140
	High	7,310	12,230	1,940	20	14,190	6,580	3,120
	Avg.	6,000	10,040	1,610	20	11,670	5,410	2,570
10.0	Low	5,010	8,380	1,340	80	9,800	4,540	2,150
	High	7,310	12,230	1,940	80	14,250	6,610	3,130
	Avg.	6,000	10,040	1,610	80	11,730	5,440	2,580
11.5	Low	5,010	8,380	1,340	240	9,960	4,620	2,190
	High	7,310	12,230	1,940	240	14,410	6,680	3,170
	Avg.	6,000	10,040	1,610	240	11,890	5,510	2,610

[a] Service life of pavement, 26 yr; life of asphalt concrete resurfacing, 13 yr; analysis period, 39 yr; thickness of asphalt concrete resurfacing for pavements, 3 in., and for shoulders, 2 in.

TABLE 12

RESURFACING COSTS PER MILE FOR 2-LANE WIDTH OF FLEXIBLE PAVEMENT AND FOR SHOULDERS[a]

Traffic Index	1960 Contracts: Price Rating	1960 Contracts: Costs per Mile ($)	Costs at End of 13th Yr (2% price-trend factor = 1.2936) ($)	Costs for Engg. (10%) and Suppl. Work (6%) ($)	Traffic Delay and Accident Costs ($)	Total Resur. Costs at End of 13th Yr ($)	Present Worth Resur. Costs: Int. at 3% ($)	Present Worth Resur. Costs: Int. at 6% ($)
			(a) Pavement Resurfacing Costs per Mile					
8.5	Low	6,760	8,750	1,400	10	10,160	6,920	4,760
	High	9,720	12,570	2,010	10	14,590	9,940	6,840
	Avg.	8,030	10,390	1,660	10	12,060	8,210	5,650
10.0	Low	6,760	8,750	1,400	70	10,220	6,960	4,790
	High	9,720	12,570	2,010	70	14,650	9,980	6,870
	Avg.	8,030	10,390	1,660	70	12,120	8,250	5,680
11.5	Low	6,760	8,750	1,400	200	10,350	7,050	4,850
	High	9,720	12,570	2,010	200	14,780	10,070	6,930
	Avg.	8,030	10,390	1,660	200	12,250	8,340	5,740
			(b) Shoulder Resurfacing Costs per Mile					
8.5	Low	3,290	4,260	680	10	4,950	3,370	2,320
	High	4,850	6,270	1,000	10	7,280	4,960	3,410
	Avg.	3,940	5,100	820	10	5,930	4,040	2,780
10.0	Low	3,290	4,260	680	50	4,990	3,400	2,340
	High	4,850	6,270	1,000	50	7,320	4,980	3,430
	Avg.	3,940	5,100	820	50	5,970	4,070	2,800
11.5	Low	3,290	4,260	680	150	5,090	3,470	2,390
	High	4,850	6,270	1,000	150	7,420	5,050	3,480
	Avg.	3,940	5,100	820	150	6,050	4,120	2,840

[a]Service life of pavement, 13 yr; life of resurfacing, 13 yr; analysis period, 26 yr; thickness of asphalt concrete resurfacing for pavement, $1\frac{1}{2}$ in., and for shoulders, $1\frac{1}{4}$ in.

TABLE 13

RESURFACING COSTS PER MILE FOR 2-LANE WIDTH (24 Ft) OF FLEXIBLE PAVEMENT[a]

Traffic Index	1960 Contracts: Price Rating	1960 Contracts: Costs per Mile ($)	Costs at End of 18th Yr (2% price-trend factor = 1.4282) ($)	Costs at End of 31st Yr (2% price-trend factor = 1.8476) ($)	Costs for Engg. (10%) and Suppl. Work (6%) ($)	Traffic Delay and Accident Costs ($)	Total Resur. Costs at End of 18th Yr ($)	Total Resur. Costs at End of 31st Yr ($)	Present Worth ($): First Resur. Costs: Int. at 3%	Present Worth ($): First Resur. Costs: Int. at 6%	Present Worth ($): Second Resur. Costs: Int. at 3%	Present Worth ($): Second Resur. Costs: Int. at 6%
				(a) First Pavement Resurfacing Cost per Mile								
8.5	Low	6,760	9,650		1,540	10	11,200		6,580	3,920		
	High	9,720	13,880		2,220	10	16,110		9,460	5,640		
	Avg.	8,030	11,470		1,840	10	13,320		7,820	4,670		
10.0	Low	6,760	9,650		1,540	70	11,260		6,610	3,940		
	High	9,720	13,880		2,220	70	16,170		9,500	5,660		
	Avg.	8,030	11,470		1,840	70	13,380		7,860	4,690		
11.5	Low	6,760	9,650		1,540	200	11,390		6,690	3,990		
	High	9,720	13,880		2,220	200	16,300		9,570	5,710		
	Avg.	8,030	11,470		1,840	200	13,510		7,940	4,730		
				(b) Second Pavement Resurfacing Cost per Mile								
8.5	Low	6,760		12,490	2,000	10		14,500			5,800	2,380
	High	9,720		17,960	2,870	10		20,840			8,340	3,420
	Avg.	8,030		14,840	2,370	10		17,220			6,890	2,830
10.0	Low	6,760		12,490	2,000	70		14,560			5,820	2,390
	High	9,720		17,960	2,870	70		20,900			8,360	3,430
	Avg.	8,030		14,840	2,370	70		17,280			6,910	2,840
11.5	Low	6,760		12,490	2,000	200		14,690			5,880	2,410
	High	9,720		17,960	2,870	200		21,030			8,410	3,460
	Avg.	8,030		14,840	2,370	200		17,410			6,960	2,860

[a]Service life of pavement, 18 yr; life of resurfacings, 13 yr; analysis period, 39 yr; thickness of asphalt concrete resurfacings, $1\frac{1}{2}$ in.

TABLE 14

RESURFACING COSTS PER MILE FOR SHOULDERS FOR 2-LANE FLEXIBLE PAVEMENT[a]

Traffic Index	1960 Contracts: Price Rating	1960 Contracts: Costs per Mile ($)	Costs at End of 18th Yr (2% price-trend factor = 1.4282) ($)	Costs at End of 31st Yr (2% price-trend factor = 1.8476) ($)	Costs for Engg. (10%) and Suppl. Work (6%) ($)	Traffic Delay and Accident Costs ($)	Total Resur. Costs at End of 18th Yr ($)	Total Resur. Costs at End of 31st Yr ($)	Present Worth ($): First Resur. Costs, Int. at 3%	Present Worth ($): First Resur. Costs, Int. at 6%	Present Worth ($): Second Resur. Costs, Int. at 3%	Present Worth ($): Second Resur. Costs, Int. at 6%
(a) First Shoulder Resurfacing Costs per Mile												
8.5	Low	3,290	4,700		530	10	5,240		3,080	1,840		
	High	4,850	6,930		780	10	7,720		4,530	2,700		
	Avg.	3,940	5,630		630	10	6,270		3,680	2,200		
10.0	Low	3,290	4,700		530	50	5,280		3,100	1,850		
	High	4,850	6,930		780	50	7,760		4,560	2,720		
	Avg.	3,940	5,630		630	50	6,310		3,710	2,210		
11.5	Low	3,290	4,700		530	150	5,380		3,160	1,880		
	High	4,850	6,930		780	150	7,860		4,620	2,750		
	Avg.	3,940	5,630		630	150	6,410		3,770	2,250		
(b) Second Shoulder Resurfacing Costs per Mile												
8.5	Low	3,290		6,080	970	10	7,060	7,060			2,820	1,160
	High	4,850		8,960	1,430	10	10,400	10,400			4,160	1,710
	Avg.	3,940		7,280	1,160	10		8,450			3,380	1,390
10.0	Low	3,290		6,080	970	50		7,100			2,840	1,170
	High	4,850		8,960	1,430	50		10,440			4,180	1,720
	Avg.	3,940		7,280	1,160	50		8,490			3,400	1,390
11.5	Low	3,290		6,080	970	150		7,200			2,880	1,180
	High	4,850		8,960	1,430	150		10,540			4,220	1,730
	Avg.	3,940		7,280	1,160	150		8,590			3,440	1,410

[a] Service life of pavement, 18 yr; life of asphalt concrete resurfacings, 13 yr; analysis period, 39 yr; average thickness of asphalt concrete resurfacings, $1\frac{1}{4}$ in.

for both the traveled way portion and the shoulder portion was the same as the thickness adopted for the second resurfacing of flexible pavements and shoulders.

For resurfacing the shoulders of flexible pavements, a thickness of 1½ in. was used at the edge of the traveled way which was tapered to a 1-in. thickness at the outer edge of the shoulder for the first resurfacing. Where a second resurfacing of flexible pavements was required, the thickness of both the traveled way portion and the shoulder portion was the same as the thickness adopted for the first resurfacing of flexible pavements.

The construction costs for resurfacing both pavement types were computed in terms of the same 1960 unit contract prices which were used to compute the initial asphalt concrete paving costs. However, to determine the total cost of resurfacing, the three new resurfacing cost items adopted by the California Division of Highways in 1963 mentioned earlier in this paper were incorporated in this study. Thus, as is indicated in Tables 10 to 14, the total resurfacing costs for this study were computed on the basis of (a) the cost per mile for the given thickness of resurfacing using the 1960 unit prices for asphalt concrete pavement construction, (b) the increased cost for future resurfacing resulting from the application of a 2 percent compound interest price trend factor, (c) the increased cost for future resurfacing resulting from a 10 percent charge for preliminary and construction engineering work and from a 6 percent charge for supplemental work made necessary by the resurfacing, and (d) the cost of traffic delay and traffic accidents resulting from resurfacing operations. The increased costs for preliminary and construction engineering and for supplemental work were expressed as a percent of the future resurfacing cost. It should be noted in Tables 10 to 14 that all future resurfacing costs were converted to present worth costs by the use of 3 percent and 6 percent compound interest rates.

All of the values used in computing the resurfacing costs were based on California data which for certain items have only recently been made the subject of special study. The resurfacing cost item which is most likely to be questioned, especially by economists, is the increased cost resulting from the application of a 2 percent compound interest price-trend factor. Thus, for resurfacing at the end of the 18th year, the 1960 costs were increased 42.8 percent; at the end of the 26th year, the increase was 67.3 percent; and for resurfacing at the end of the 31st year, the 1960 costs were increased by 84.8 percent. It is evident that the 2 percent price-trend factor will result in a substantial increase in resurfacing costs and that special consideration should be given to the advisability of using such a factor in other studies, and its amount if used. In the following discussion some of the arguments for and against the adoption of a price-trend factor are presented.

In the Federal Interagency report (11) on Proposed Practices for Economic Analysis of River Basin Projects, a committee composed of some of the nation's leading economists recommended that in making benefit-cost analyses for the evaluation of Federal public works projects, "prices should be used which may reasonably be expected to prevail at the time costs are incurred and at the time benefits are realized, in terms of a constant general price level." The Committee also recommended that projected prices should be used for evaluating project benefits as well as costs of maintenance, replacements and deferred construction. However, representatives of several Federal agencies recommended that current prices should be used in estimating all benefits and costs until improved procedures are developed for estimating long-range price projections.

Highway construction costs as indicated by the California Highway Cost Index increased at an average rate of 4½ percent compounded annually for the period from 1940 to 1962. A large part of this increase was brought about as the result of inflation or the depreciation in value of the dollar. During the past 10 years the California Highway Cost Index and the average cost of pavement construction increased at an average rate of 2 percent compounded annually. During this period the general price level was fairly stable and it was partly for this reason that a 2 percent price-trend factor for resurfacing costs was adopted for this study. Another reason for applying a 2 percent price-trend factor was to make allowance for the increased future resurfacing costs which are likely to result from the depletion of the best and most accessible sources of paving materials in California. At the present accelerated rate of highway construction, many of the best sources of paving materials are being exhausted. To develop new sources of paving materials will, in many areas, increase the cost of these materials. The costs of processing the materials to meet specifications and of shipping them over greater distances may also increase their cost.

Estimating future resurfacing costs is complicated by the possibility that technological improvements in plant operations and in the construction of pavements may offset in part the increased cost of future resurfacing referred to above. The authors adopted the 2 percent price-trend factor currently being used by the California Division of Highways, recognizing that it represents a value judgment which is open to question. In a critical evaluation of pavement costs, the adoption of a price-trend factor should be given special consideration for projects where unit costs might rise substantially for such reasons as the decreasing accessibility and availability of suitable paving materials.

The 10 percent charge for preliminary and construction engineering work required in connection with resurfacing and the 6 percent charge for supplemental work represent average or typical charges for this type of work on state highways in California. The preparation of plans and specifications, the letting of contracts, the testing of materials, providing inspection and engineering supervision on the project, are cost items which can be estimated fairly accurately for a given project. The supplemental work which includes traffic handling, placing temporary traffic stripes and traffic signs or signals, replacing permanent traffic stripes, the protection or temporary removal of guardrail and guide posts, and the adjustment or reconstruction of various drainage structures or facilities will vary for each project and instead of using a 6 percent charge, an itemized estimate of the cost of supplemental work should preferably be made for each project.

The traffic delay and accident costs resulting from resurfacing operations adopted for this study were based on California's limited experience in collecting this type of cost data. Traffic delays caused by maintenance and resurfacing operations are now under investigation by the Division of Highways Traffic Department and it is expected that more accurate and reliable data will be available within a year or two. It should be noted in Tables 10 to 14 that the estimated traffic delay and accident costs were assigned the low value of $20 per mile of rigid pavement for light-duty roads and were increased to $300 per mile of rigid pavement for heavy-duty roads. Due to the reduction in resurfacing thickness of the asphalt concrete pavements and the reduction in time required for resurfacing these pavements, the traffic delay costs for the flexible pavements were reduced approximately in proportion to the change in the thickness of the resurfacing of the two pavement types. For the same reason, the traffic delay and accident costs for resurfacing shoulders were lower than the same costs for resurfacing the traveled way portion of the roadway.

In comparing the various charges for resurfacing given in Tables 10 to 14, it is evident that the charges for traffic delay and accident costs used in this study are so small that for all practical purposes they could have been omitted. An important consideration, however, in this connection is that in the selection of pavement type for urban freeways with traffic volumes ranging from 50,000 to 200,000 vehicles per day, portland cement concrete has generally been selected as the preferred pavement type in California because the traffic delays and accident hazards created by pavement repairs and resurfacing have been assumed to be much greater on asphalt concrete pavements than on portland cement concrete pavements. This study indicated that the magnitude and importance of the traffic delay and accident costs in the selection of pavement type for urban freeways have been greatly exaggerated. There is evident need for conducting factual studies to determine the true nature of these costs.

As in many other highway cost studies involving traffic accidents, it will be very difficult to establish the traffic accident costs caused by resurfacing. Nevertheless, it is important that studies to determine the accident experience in connection with pavement repairs and resurfacing operations be conducted to ascertain the nature and extent of these accidents. Maintenance departments have in recent years developed traffic control safeguards which are reducing traffic delays and the accident hazards on freeways caused by pavement repairs and resurfacing operations. While the use of extensive specially developed traffic control measures will increase the cost of resurfacing, they should contribute to a reduction in the accident hazards and the accident costs and make it possible to obtain a more accurate estimate of the accident costs to be charged against the resurfacing operations.

Maintenance Costs

The maintenance costs for this study were assumed to cover all routine and periodic maintenance of the traveled way and shoulder portion of the roadway, expressed in terms of the average annual maintenance cost per mile of 2-lane roadway. The maintenance costs for each pavement type are given in Tables 15, 16, 17, and 18. For the portland cement concrete pavements with service lives of 18 and 26 years and an analysis period of 26 years, an average annual maintenance cost of $320 per mile was used. For a 39-yr analysis period, the average annual cost was increased to $370

TABLE 15

ANNUAL COSTS OF A 2-LANE MILE OF PORTLAND CEMENT CONCRETE PAVEMENT AND SHOULDERS FOR NINE TYPICAL DESIGN SECTIONS FOR A 26-YR ANALYSIS PERIOD[a]

Design Section			Contract Price Rating	Annual Costs of Pavement and Shoulders for 26-Yr Analysis Period				
No.	R-Value of Soil	Traffic Index		Initial Construction Costs ($)		Maintenance Costs ($)	Total Annual Costs per Mile ($)	
				3%	6%		3%	6%
1	R 5	8.5	Low	3,380	4,650	320	3,700	4,970
			High	5,720	7,870	320	6,040	8,190
			Avg.	4,320	5,940	320	4,640	6,260
2		10.0	Low	4,040	5,550	320	4,360	5,870
			High	6,840	9,420	320	7,160	9,740
			Avg.	5,190	7,130	320	5,510	7,450
3		11.5	Low	4,110	5,660	320	4,430	5,980
			High	7,140	9,830	320	7,460	10,150
			Avg.	5,330	7,340	320	5,650	7,660
7	R 35	8.5	Low	3,300	4,540	320	3,620	4,860
			High	5,420	7,460	320	5,740	7,780
			Avg.	4,170	5,730	320	4,490	6,050
8		10.0	Low	3,890	5,350	320	4,210	5,670
			High	6,250	8,590	320	6,570	8,910
			Avg.	4,890	6,720	320	5,210	7,040
9		11.5	Low	3,970	5,460	320	4,290	5,780
			High	6,550	9,010	320	6,870	9,330
			Avg.	5,030	6,930	320	5,350	7,250
13	R 65	8.5	Low	3,080	4,230	320	3,400	4,550
			High	4,520	6,220	320	4,840	6,540
			Avg.	3,720	5,110	320	4,040	5,430
14		10.0	Low	3,670	5,040	320	3,990	5,360
			High	5,350	7,360	320	5,670	7,680
			Avg.	4,440	6,110	320	4,760	6,430
15		11.5	Low	3,670	5,040	320	3,990	5,360
			High	5,350	7,360	320	5,670	7,680
			Avg.	4,440	6,110	320	4,760	6,430

[a] Interest at 3 and 6%; service life of portland cement concrete pavement = 26 yr.

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